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Small Explorer (SMEX)

POsitron Electron Magnet Spectrometer (POEMS)

p 165

Phase I Final Report

NASA Contract
NAS5-38098

Not SBIR

Prepared by the
Bartol Research Institute
University of Delaware
Newark, DE 19716

January 1995

Small Explorer (SMEX)
POsitron Electron Magnet Spectrometer (POEMS)

Phase I Final Report

Signatures

Prepared by: Jacques L'Heureux 1/31/95

Jacques L'Heureux Date
Instrument Manager

Paul A. Evenson Jan 31, 1995

Paul A. Evenson Date
Principal Investigator

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Final Report from the Bartol Research Institute:

Phase I was from December 1993 to October 1994 with funding extended to December 1994. The SMEX/POEMS Team consist of five US and of three European groups. The collaborating institutions, the Lead Co-Is and their institution's abbreviated names are listed in Table 1.

Table 1 Collaborating Institutions and their Abbreviated Names

Institution/Lead Co-I	Abbreviated Name
Bartol Research Institute Paul A. Evenson, POEMS PI	Bartol or BRI
GSFC - Laboratory for High Energy Astrophysics Louis M. Barbier, Lead Co-I	GSFC/LHEA
Louisiana State University John P. Wefel, Lead Co-I	LSU
University of Arizona J. Randy Jokipii, Lead Co-I	Arizona or UA
University of Chicago Simon P. Swordy, Lead Co-I	Chicago or UC
Commissariat a l'Energie Atomique, Saclay Philippe Ferrando, Lead Co-I	CEA-Saclay or CEA
University of Kiel Horst Kunow, Lead Co-I	Kiel or UK
University of Turku Jarmo Torsti, Lead Co-I	Turku or UT

The Bartol Research Institute (BRI) was awarded the full contract amount in December of 1993 and subcontracts were set up later that month with the four other US institutions. Approximately one man-month of time was expended on setting up those four subcontracts.

The work that I will summarize from here on refers to that done by BRI personnel and by the group as a whole. Work done by the BRI subcontractors is summarized in the attached appendices. More information can also be found in the proposal that we submitted in July of 1994 as document BRI-SMEX-010 (Volume 1 - Technical Proposal and Volume 2 - Cost Proposal). Copies of these documents will be made available if requested.

The month of January was mainly devoted to instrument definition. A group meeting between the 8 institutions was held at the Bartol Research Institute on January 11-12 which was followed by the Technical Interchange Meeting with the SMEX Project Office (PO) on January 13-14. Material presented at these meetings are collected in the document BRI-SMEX-001 on file at BRI.

From then until the next Science Team Meeting on February 9-10, a considerable effort was devoted to finalizing the design of the instrument, defining the mission and reviewing the requirements that it imposed on the mission (and spacecraft). This culminated with the Mission Requirements Review on February 11 at GSFC with the SMEX PO. A draft of the Mission Requirement Document (MRD) was reviewed at that meeting. Material presented at these two meetings are collected in the document BRI-SMEX-002 on file at BRI.

The month of March was spent doing instrument simulations and calculating radiation levels for the proposed orbit. In addition, the double Mass Spectrometer (MS) design was replaced by a single MS mainly for weight considerations. This work culminated with a Science Team Meeting on March 22-23 and a Mission Concepts Review with the PO on March 21. Material presented at these meetings are collected in the document BRI-SMEX-003 on file at BRI.

The Mission Requirements Document for POEMS was signed on April 20, 1994 by Bartol and the Project Office.

The month of May was devoted to the study of a possible combined mission for POEMS and TRACE. The mission was to be called TRAPEM and was extensively discussed at a Science Team Meeting on May 2-3 and at a Requirements Review with the PO on May 4. Material presented at these meetings are collected in the document BRI-SMEX-004 on file at BRI.

The combined mission was abandoned shortly thereafter and both POEMS and TRACE teams returned to their separate concepts. The team is now busily working on Phase III/IV schedule and is developing a cost estimate. These were reviewed at a Team Meeting in Kiel, Germany on June 20-22. GEANT simulations of the EES detector were also presented. Material presented at this meeting are collected in the document BRI-SMEX-005 on file at BRI.

A Mission Implementation Plan Review was held at the University of Chicago on July 21. At that meeting, the team presented its hardware implementation plan, its fabrication and test schedule, its data processing plan and its cost estimates with a spending profile. Material presented at this meeting are collected in the document BRI-SMEX-006 on file at BRI.

A preliminary Payload Assurance Implementation Plan (PAIP) was also delivered to the PO in this time frame.

On August 5, the POEMS team and the project team from GSFC had a combined Mission Implementation Review by the GSFC Engineering Directorate. Viewgraphs presented at that meeting are on file at BRI.

On August 24, the POEMS PI and the Project Director for SMEX presented the SMEX/POEMS mission to the Astrophysics and Space Physics directors of the Office of Space Science at NASA Headquarters. Viewgraphs presented at that meeting are on file at BRI.

On September 1, the POEMS PI gave the final presentation to the Associate Administrator for the Office of Space Science at NASA Headquarters. A copy of the viewgraphs presented are included here in Appendix E.

Later that month, the announcement was made that POEMS had not been chosen and that Phase II of the contract would not be exercised.

The remaining time in the contract was used to close out the subcontracts with our collaborators and to write this final report.

The final reports from the four US institutions under subcontract to Bartol are included here as appendices A to D. A good description of the instrument and of the mission planned for it as well as the proposed schedule and data analysis plans can be found in those reports.

January 31, 1994

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Appendix A

Final Report from the Louisiana State University

POsitron Electron Magnet Spectrometer (POEMS)

A Small Explorer Mission (SMEX)

Final Report

for Subcontract 26053-EX to NASA Contract NAS5-38098

Submitted to

Bartol Research Institute
University of Delaware

by

John P. Wefel and T. Gregory Guzik
Department of Physics and Astronomy
Louisiana State University
Baton Rouge, LA 70803-4001

30 November 1994

Summary

This report covers the activities of Louisiana State University under subcontract 26053-EX between LSU and the Bartol Research Institute (Bartol), which began 1 January 1994. The purpose of this subcontract was for LSU to participate in and support Bartol in the work to define the SMEX/POEMS spaceflight mission under NASA Contract NAS5-38098 between NASA and Bartol. LSU's role(s) in this Phase-I definition effort was the evaluation of the radiation environment, orbit/altitude determination, count rate and data rate evaluation, "signal to noise" studies for the magnet spectrometer (MS) subsystem, and development of the data processing and analysis component for the SMEX/POEMS Mission, should it have been selected for flight.

The conclusions of this study were that for a 1998 launch into a 600 km altitude, 98°, approximately sun synchronous orbit, (a) the total radiation dose would be typically a few k-rad per year, certainly < 20 k-rad per year for the anticipated shielding and potential solar flare environment, (b) detector counting rates would be dominated by the South Atlantic Anomaly (SAA) and the horns of the Van Allen belts, (c) the galactic electron and positron "signal" can be extracted from the albedo background and the trapped populations by detailed evaluation of the geomagnetic transmission function (cut-off) for each event, (d) POEMS could make significant contributions to magnetospheric science if sufficient down-link capacity were provided and (e) a fully functioning, cost efficient, data processing and analysis facility design was developed for the mission. Overall, POEMS was found to be a relatively simple experiment to manifest, operate and analyze and had potential for fundamental new discoveries in cosmic, heliospheric, solar and magnetospheric science.

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POEMS/SMEX

I. INTRODUCTION

The POsitron Electron Magnet Spectrometer (POEMS) Investigation was submitted in response to NASA AO OSSA 2-92 and was selected as a candidate mission for the second round of the Small Explorer Program Missions. NASA initiated a Phase I instrument and mission definition contract, NAS5-38098, with the Bartol Research Institute (Bartol), University of Delaware, the lead institution for the investigation. Bartol awarded a subcontract (26053-EX) to Louisiana State University (LSU) to assist in the mission definition studies, working with the POEMS team and the SMEX office at GSFC.

POEMS is a joint US-European effort. The team consists of:

- Bartol Research Institute, USA (Lead Institution)
- University of Kiel, Germany (Lead European Institution)
- CEA, Service d'Astrophysique, Saclay, France
- Goddard Space Flight Center, USA
- Louisiana State University, USA
- University of Arizona, USA
- University of Chicago, USA
- University of Turku, Finland

Different institutions provide portions of the overall hardware, software and analysis needed for the success of the project. LSU's role is principally in the development of the data processing system, handling/distribution of the flight data and submission of the final data and science products to the NASA archive. All institutions participate in the science analysis and publication of the results.

In the initial selection, NASA picked four potential SMEX Missions, JUNO, POEMS, TRACE and WIRE, all to undergo a Phase I definition study. Based upon the proposal, the cost, the mission plan and the GSFC/SMEX office assessment which were all submitted to GSFC, NASA Headquarters selected two of the four - - TRACE and WIRE - - to move ahead to launch and data acquisition. Thus, this document represents the final report on the LSU effort for the POEMS Phase I definition.

The LSU subcontract required the following deliverables to be provided:

REVIEWS AND PLANS

1. Technical Interchange Meeting Input
2. Input to Mission Requirements Review
3. Input to Mission Concept Review
4. Input to Systems Requirements Review
5. Input to Mission Implementation Plan Review
6. Input to Instrument/Spacecraft ICD

7. Input to Mission Requirements Document

8. Input to Implementation Plan

REPORTS

9. a) Monthly Progress Reports

   b) Quarterly Progress Reports

10. Final Report Phase I Definition Study

11. a) Monthly Financial Reports (533M)

    b) Final Financial Report

TECHNICAL DOCUMENTATION

12. Input to Performance Assurance Implementation Plan

13. Preliminary Phase III-IV Proposal

14. Final Phase III-IV Proposal

15. Input to Presentation to the Associate Administrator

as well as input to the POEMS team meetings. With this report and the final financial report to follow, LSU has met the deliverable requirements of the project.

II. THE POEMS PACKAGE FOR A SMEX MISSION

The POEMS Investigation for a Small Explorer Mission (SMEX) was designed to make detailed measurements of anti-electrons (positrons) whose relative abundance is largely unknown. In addition, the total electron (e^+ plus e^-) spectra would be determined from below 1 MeV to beyond 10 GeV in energy.

The Small Explorer Program (SMEX) provides an opportunity for space flight of small, lightweight experiments for missions in near-Earth orbit lasting typically one year (with possible continuation for a subsequent period). The SMEX/POEMS project is a payload consisting of two instruments: the Magnet spectrometer (MS) and the Energy Extension Subsystem (EES). Together these instruments will provide a cohesive set of results to address the science objectives of the mission.

A. SCIENCE OBJECTIVES

Precise measurements of the cosmic positron-electron ratio, as a function of energy and time, are required to conquer one of the "final frontiers" in cosmic ray research. Although the total positron plus electron spectrum is relatively well measured, the ratio of positrons to electrons is not well determined either from measurements or from theoretical arguments concerning the expected ratio in cosmic rays in interstellar space. The time variations and energy dependence of this ratio hold the key to answering many basic questions concerning the origin, acceleration, and interstellar propagation of galactic cosmic rays, the interaction of the cosmic rays with the solar wind in the heliosphere (solar modulation), and the acceleration of energetic particles in solar flares, in the solar wind, and at the outer boundaries of the heliosphere.

Particle astrophysics research was cited as important for understanding violent events in the galaxy by the Astronomy Survey Committee ("Field Report"). Positron-electron measurements specifically were recommended by the NASA Cosmic Ray Program Working Group in 1982 and reaffirmed in its 1985 update "The Particle Astrophysics Program for 1985-1995". POEMS would be a major step towards achieving the scientific goals outlined by these scientific advisory groups.

The POEMS science objectives in the Cosmic, Heliospheric, Solar, and Magnetospheric disciplines are summarized below.

- **Primary Positrons.** Determine the degree to which primary sources of positrons contribute to the Galactic Cosmic Radiation.

- **Cosmic Secondary Positrons.** Utilize secondary positrons to trace the propagation history of the Galactic Cosmic Radiation.

- **Charge Sign Dependent Modulation.** Measure the charge sign dependence of heliospheric modulation using particles of the same mass and velocity.

- **Solar Modulation of Energetic Particles.** Monitor and separate those components of solar heliospheric modulation that depend only on rigidity and velocity.

- **Solar Flare Positrons.** Investigate the positron fraction among solar energetic particles emitted from different types of flares.

- **Solar Energetic Neutral Radiation.** Relate high energy gamma-ray production in solar flares to electron and positron production.

- **Magnetospheric Acceleration.** Investigate time variations and energy spectra of electron burst events and of trapped electrons.

- **Trapped Heavy Ions.** Monitor the spatial and temporal structure of the high energy trapped helium.

In addition, to these objectives achievable with POEMS alone, there is much additional science that can be accomplished by combining POEMS data with other spacecraft results. For example, the propagation of particles in the interplanetary medium can be investigated with data from well separated spacecraft, possibly POEMS combined with SOHO, WIND, ULYSSES and maybe GALILEO, depending upon which are operational during the POEMS flight period. In like manner, solar particle acceleration and propagation can also be investigated. If the ISTP/GGS spacecraft are operational, POEMS can provide data that complements these missions as well.

B. INSTRUMENTATION AND MISSION CONCEPT

The two instruments, MS and EES, for the POEMS payload each measure the electron component over different energy ranges. A schematic representation of the two instruments and associated electronics boxes mounted on the spacecraft (S/C) is shown in Figure 1. Both sensors view the zenith with opening cones of half-angle 20° (MS) and 40° (EES). The MS contains a permanent magnet that will be used to deflect the oppositely charged electrons (e^-) and positrons (e^+). Coupled with a silicon strip detector hodoscope to measure the particle trajectory, a conical gas Cherenkov counter to indicate velocity and a calorimeter of Cesium-iodide to measure the shower energy, the MS subsystem can separate e^+ and e^- over the energy range of about 20 MeV to 2 GeV.

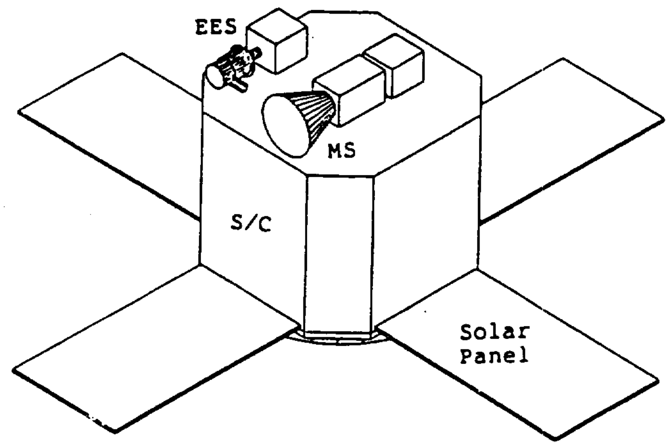


Figure 1. POEMS payload on the Spacecraft

The EES consists of a stack of silicon solid state detectors (4) of varying thickness followed by a Cesium-iodide total energy detector. The entire sensor array is enclosed within anti-coincidence scintillators. The EES can study total electrons ($e^+ + e^-$) from ~200 keV to > 30 MeV and records protons and alpha particles in the low energy region.

Both subsystems contain large Cesium-iodide detectors fully enclosed in plastic scintillator anti-coincidence shields. This provides a large sensitivity to gamma-rays which can be utilized to study solar flare events occurring during the mission.

The POEMS S/C will be launched by a Pegasus rocket into a polar orbit, nominally 600 km in altitude, with a sun-synchronous orientation. This ~98 minute orbit provides access to the low altitude magnetosphere but, most important, gives access to the low energy interplanetary particles during the polar passes twice an orbit. Over its orbit POEMS samples Galactic Cosmic Rays (GCR), Solar Energetic Particles (SEP), trapped magnetospheric particles, solar gamma rays and albedo particles from the Earth's atmosphere. The broad coverage provided by the instrumentation allows significant new measurements to be made on each of these particle populations.

Following launch, the spacecraft tracking, command and control, and data reception will be the responsibility of Goddard Space Flight Center and the Wallops Flight Facility. Bartol will become the POEMS operations center providing the day-by-day command sequencing. LSU will become the mission data center, receiving the spacecraft data, sorting, adding ephemeris and other information as required, distributing the data to the POEMS collaborations, processing the data to physics units, and combining the two instrument datastreams into a single stream. This final dataset will then be augmented with other, non-SMEX data to form a value-added dataset which will be submitted, along with the appropriate documentation and software routines to the National Space Science Data Center (NSSDC) as part of the Space Physics Data System (SPDS). The mission data would then be available for further analysis by Guest Investigators.

III. THE ORBIT AND THE RADIATION ENVIRONMENT

As part of its support of the SMEX/POEMS mission, LSU undertook a task designed to study the radiation environment, the orbital parameters, the expected counting rates (galactic cosmic rays, solar energetic particles, trapped radiation), the orbit/altitude knowledge required and the backgrounds to be expected in both the MS and the EES instruments of the payload.

A. GALACTIC COSMIC RAYS AND GEOMAGNETIC TRANSMISSION

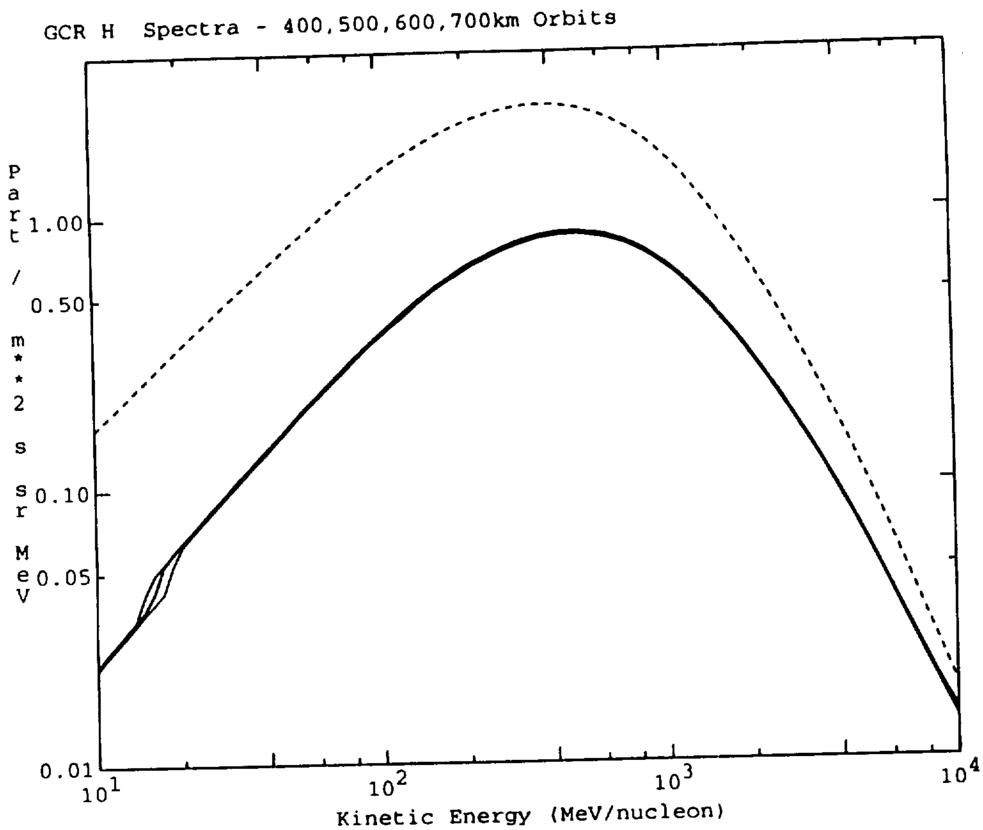
For the galactic cosmic rays (GCR), local interstellar spectra were obtained and incorporated as input into the SOLMOD solar modulation computer program. Using our previous work on solar cycle predictions, the spectrum for 1998 was calculated at the orbit of Earth. A geomagnetic transmission function was developed and applied to calculate the expected intensities at the spacecraft orbit. Evaluations were made for circular polar orbits of varying altitude. Figure 2 shows the GCR proton and helium spectra in interplanetary space (dashed) and at orbits ranging from 400-700 km in altitude. There is little difference for these components between the different altitude orbits.

Figure 3 shows the electron spectrum in interstellar space outside the heliosphere (LIS, long dash), in interplanetary space for 1998 (short dash) and in low altitude polar orbit (solid). There is a large reduction in intensity in penetrating the heliosphere, and then the Earth's magnetosphere. Note also the small bumps in the electron spectrum at low energy. These are an artifact of the transmission function calculations.

Predicting the spectrum to be observed on the SMEX Mission depends on the accuracy of the geomagnetic field transmission function employed. Figure 4 shows the transmission function both for the full orbit (solid curve) and for only magnetic latitudes greater than 65 degrees (dashed curve). This is based upon the CREME model which uses a calculated worldwide grid of geomagnetic cut-off values to interpolate for positions in a specific orbit. The two discontinuities in Figure 4 (c. f. Figure 3) had to be analyzed since they affect the low energy electrons which are the focus of POEMS.

These discontinuities prompted a review of the geomagnetic transmission question. The transmission was studied in the Störmer approximation, as a function of zenith and azimuth angles and as a function of latitude and longitude. This provided a fuller understanding of the particle penetration process, and resolved the issue of the glitches in Figure 4. Basically, the grid interpolation scheme in CREME was ineffective at high magnetic latitudes (low rigidities) and had to be modified. When this was accomplished, the discontinuities in Figures 3 and 4 were eliminated. What this effort did indicate, however, is that detailed trajectory tracing in accurate models of the Earth's magnetic field will be needed to fully analyze the POEMS data.

With the anticipated 1998 cosmic ray intensity and the corrected geomagnetic transmission function, we can predict the event rate for galactic positrons and electrons in POEMS. A sample calculation for one 27 day solar rotation period is shown in Figure 5, which assumes only a secondary positron contribution to the ratio. The uncertainties reflect purely the event statistics and demonstrate that POEMS, with one full year of data, will be able to resolve the discrepancy in the previous balloon results.



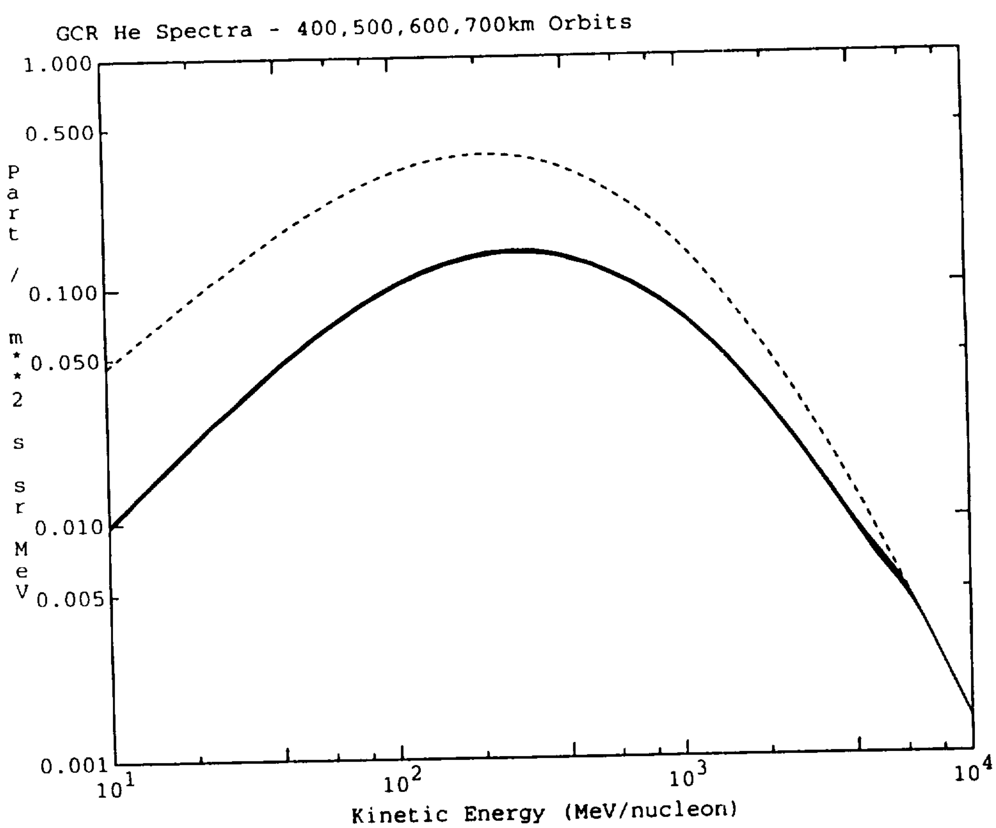


Figure 2. Calculated energy spectra in 1998 for cosmic ray H and He in interplanetary space (dashed) and in polar orbits of 400-700 km altitude (solid).

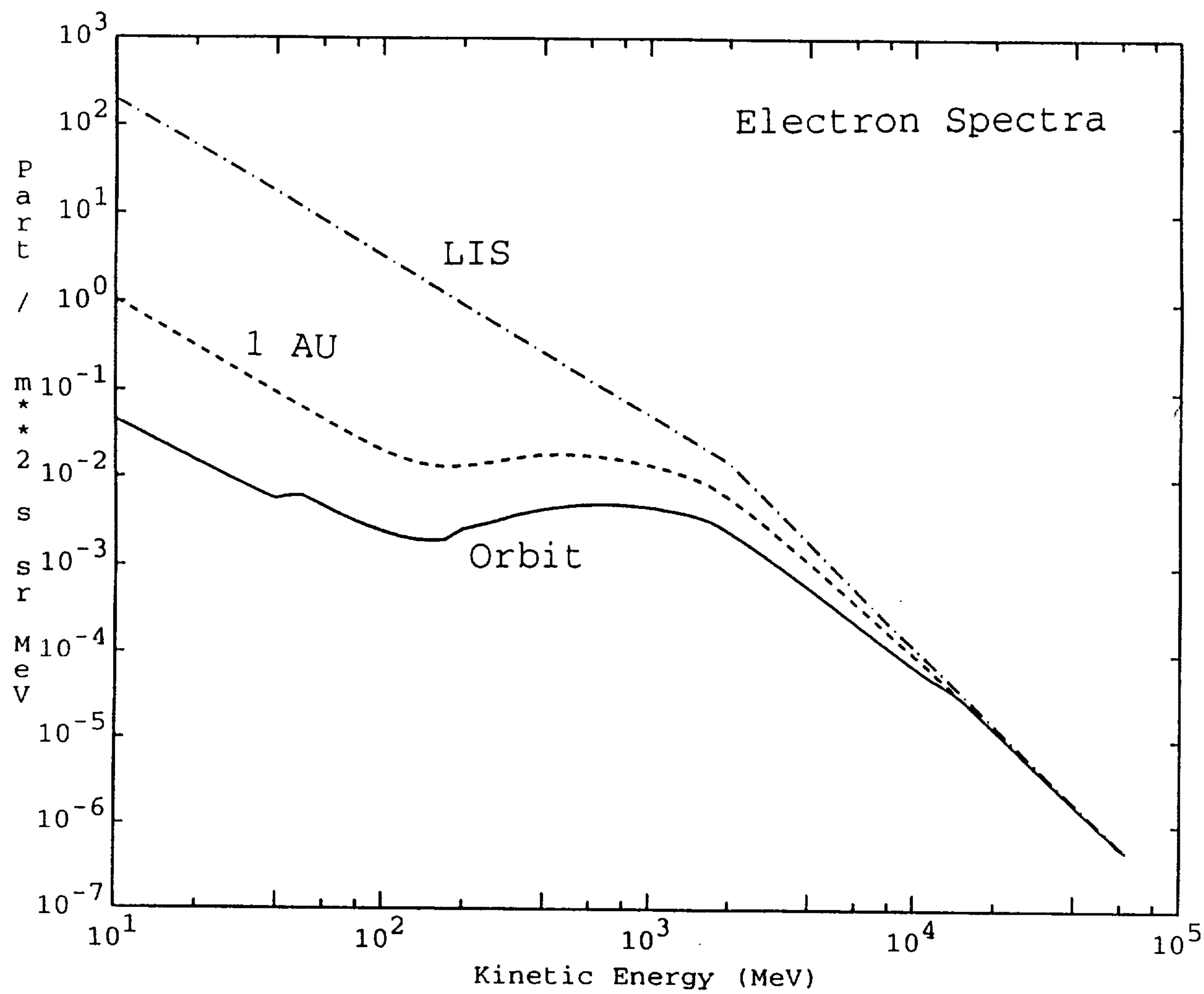


Figure 3. The electron spectrum outside the heliosphere in Local Interstellar Space (LIS, long dash), at the orbit of Earth in interplanetary space in 1998 (short dash) and in a low altitude polar orbit (solid curve).

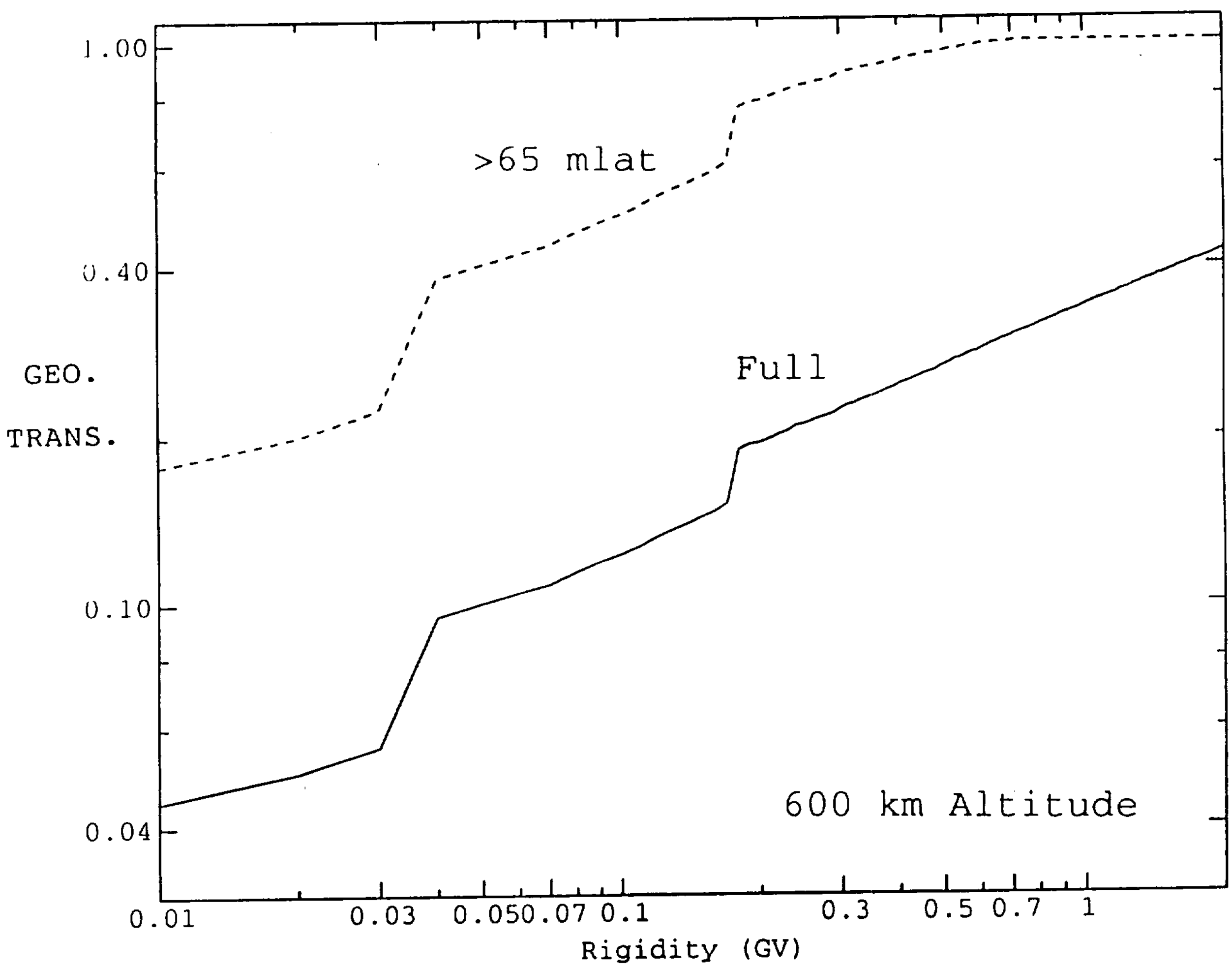


Figure 4. Geomagnetic Transmission probability as a function of rigidity for a full orbit (solid) and for only geomagnetic latitudes above 65 degrees (dashed).

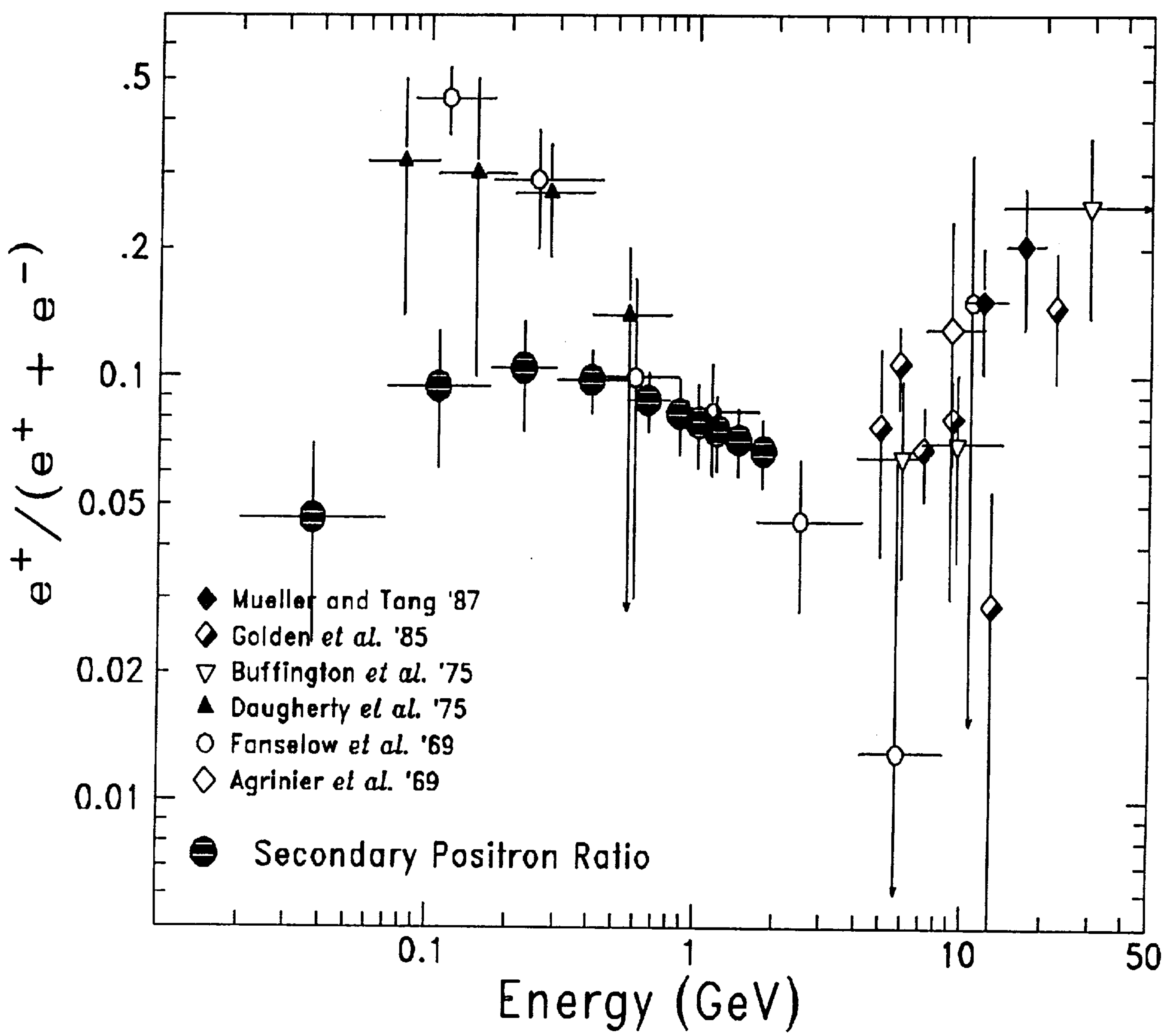


Figure 5. A sample POEMS (MS) positron-electron ratio plot as a function of energy for one 27-day period assuming purely secondary positrons.

B. SOLAR ENERGETIC PARTICLES

For solar energetic particle (SEP) emissions, flares from the CRRES mission during 1990/91 were used as examples. The ONR-604 experiment on CRRES observed, and fully characterized, 13 medium to large flares. (Another set of 13 small flares were studied as flare averages.) These were used to predict "typical" effects at the nominal orbit. For example, Figure 6 shows the energy spectra for two flares, event #5 (25 March 1991) and event #6 (13 May 1991), which differ in intensity by about an order of magnitude. Shown are the H, He and Fe spectra in interplanetary space (dashed curves) and in a 600 km altitude polar orbit. Note that, as with the GCR, there is little difference between orbits at altitudes of 400-800 km. The two flares show different spectral indices with event #5 being considerably softer than event #6.

The spectrum as well as the intensity contributes to the radiation effects that can be produced by the flares. Figure 7 shows the Linear Energy Transfer (LET) spectra for the same two flares for a range of shielding thicknesses from 0 to 1 g/cm^2 of Aluminum. The dashed curves are for the interplanetary spectra while the solid are for the spectra at 600 km altitude. The larger flare, event #5, falls off faster in the important high-LET region, but contributes more at low-LET. The conclusion is that material shielding is considerably more effective than geomagnetic shielding in reducing the radiation effects from solar flares.

This is illustrated in Figure 8 which shows a calculation of the dose delivered to one of the silicon strip detectors by SEP #5 as a function of shielding thickness. For an unprotected detector, the dose is quite large, but even for very minimal material shielding the detector (e.g. 0.1 g/cm^2) the dose is reduced below one k-rad.

C. TRAPPED PARTICLE POPULATIONS

For the trapped particle components (protons and electrons), the calculations of Stassinopoulas and Barth (1989) were employed. These authors tabulated spectra and dose for a variety of conditions, calculational modes and orbits. The radiation effects are due to three sources, trapped electrons (51%), bremsstrahlung (< 1%) and trapped protons (49%). The numbers in parenthesis give the fraction of the dose contributed by each source for a 600 km orbit and 1 g/cm^2 of shielding. For lesser shielding, the electrons become more important and the total dose increases.

For a polar orbit under solar minimum conditions (no solar flares) and using a shield thickness of 1 g/cm^2, the total dose expected, as a function of altitude is given in Table 1.

Table 1. Trapped Particle Dose

ALTITUDE (km)	TOTAL DOSE (krad/yr)
200	0.094
300	0.142
400	0.222
500	0.345
600	0.532
800	1.127
1200	4.060

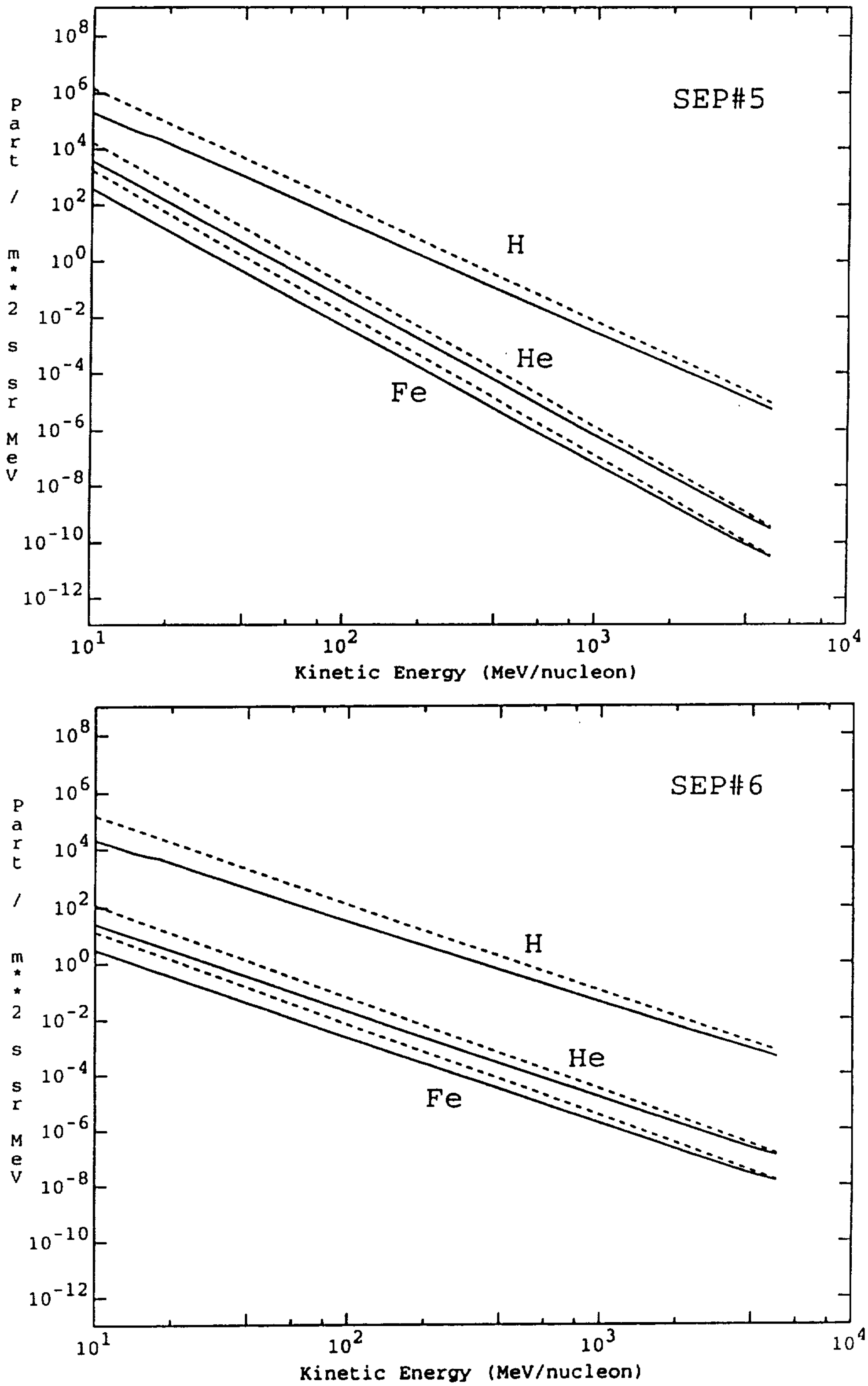
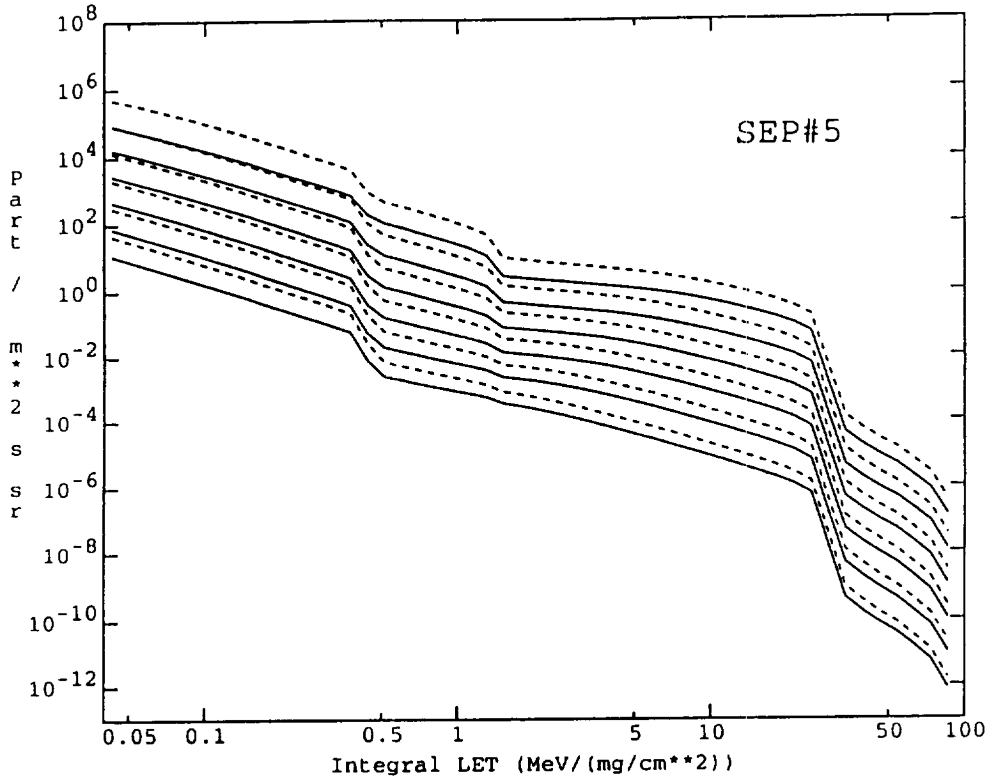


Figure 6. Flare energy spectra for the species (from top) H, He and Fe for CRRES events #5 and #6. The dashed curves show interplanetary spectra while the solid curves show the spectra in a 600 km polar orbit.



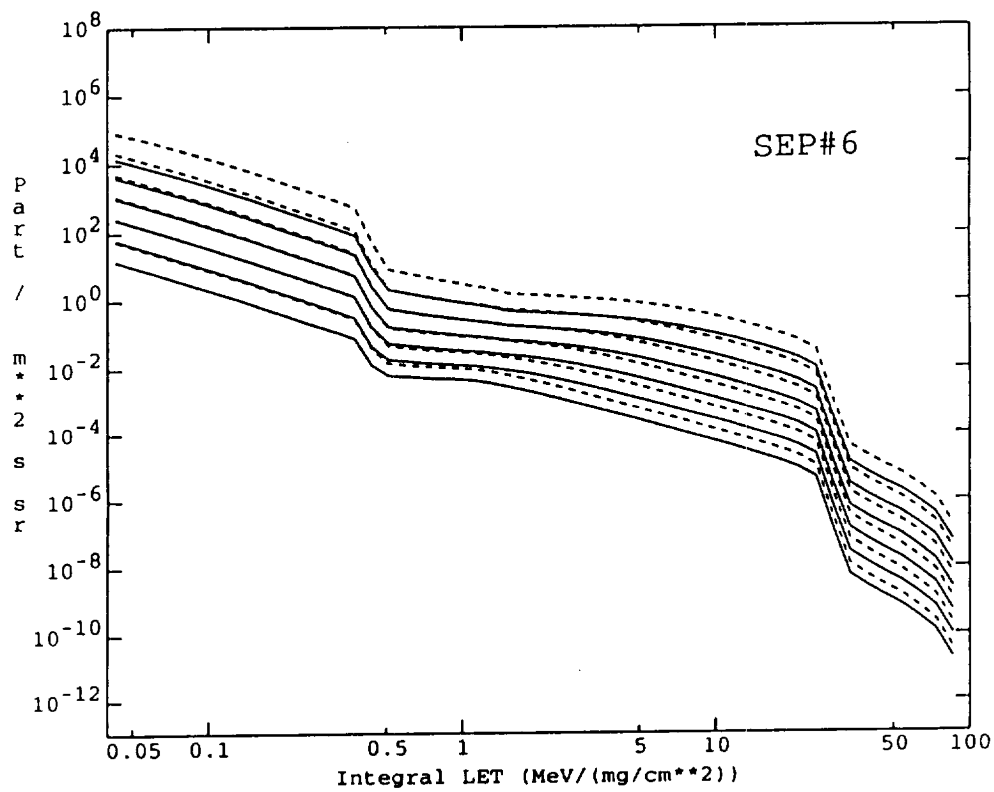


Figure 7. LET spectra for the flares of Figure 6. Dashed curves use interplanetary energy spectra while solid curves use spectra in a 600 km polar orbit. The different pairs correspond to a range of Aluminum shield thicknesses from 0 - 1 g/cm^2.

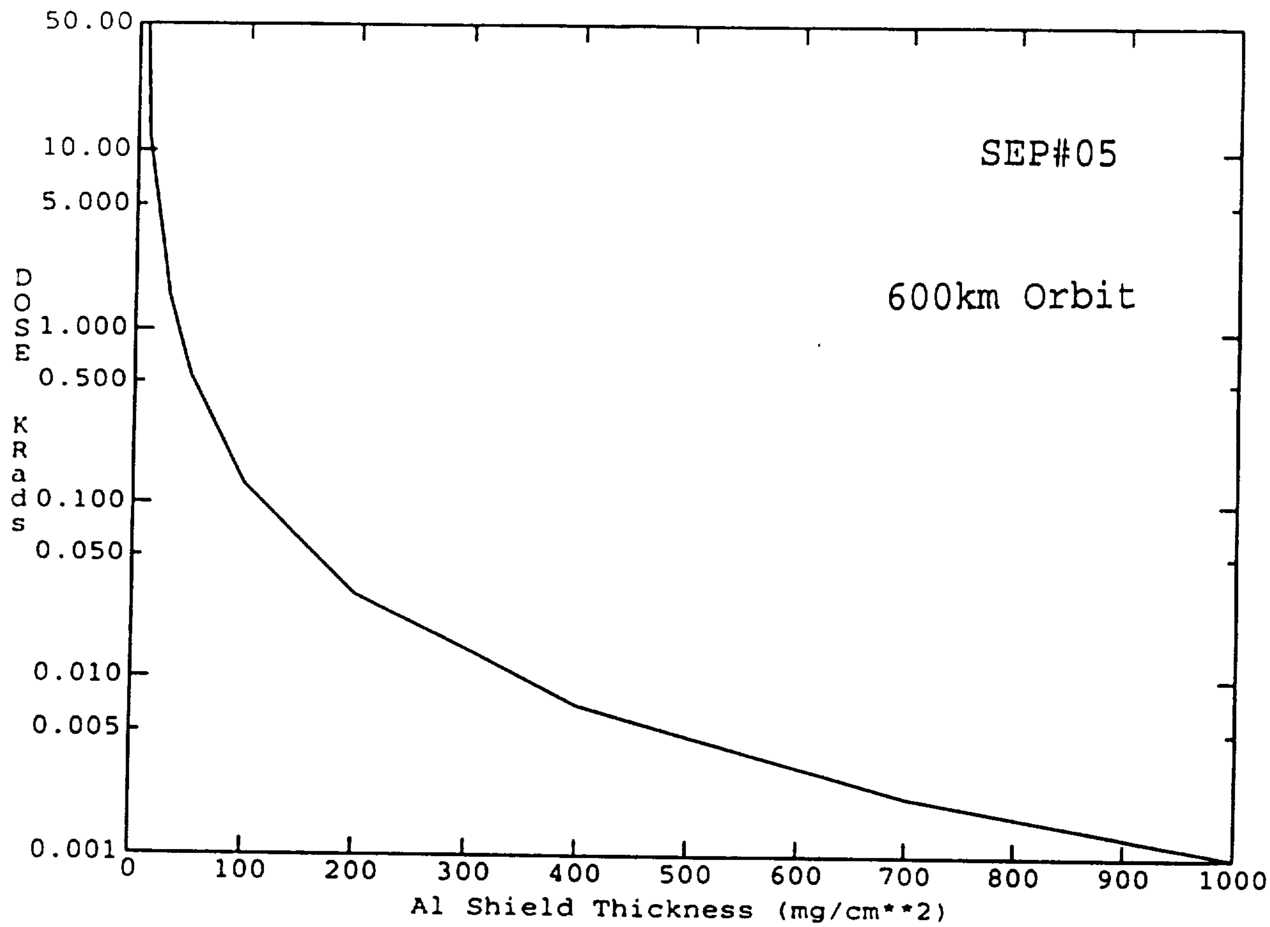


Figure 8. Calculated dose (k-rad) to one of the silicon strip detector hodoscope layers from SEP event #5 as a function of the Aluminum shielding thickness protecting the detector.

The altitude dependence comes from the orbit intercepting more intense regions of the South Atlantic Anomaly and, more of the high latitude 'horns' of the Van Allen belts as the altitude increases. This dependence is illustrated graphically in Figure 9, from Stassinpoulas and Barth (1989), where 5 year doses are shown for both solar maximum and solar minimum conditions.

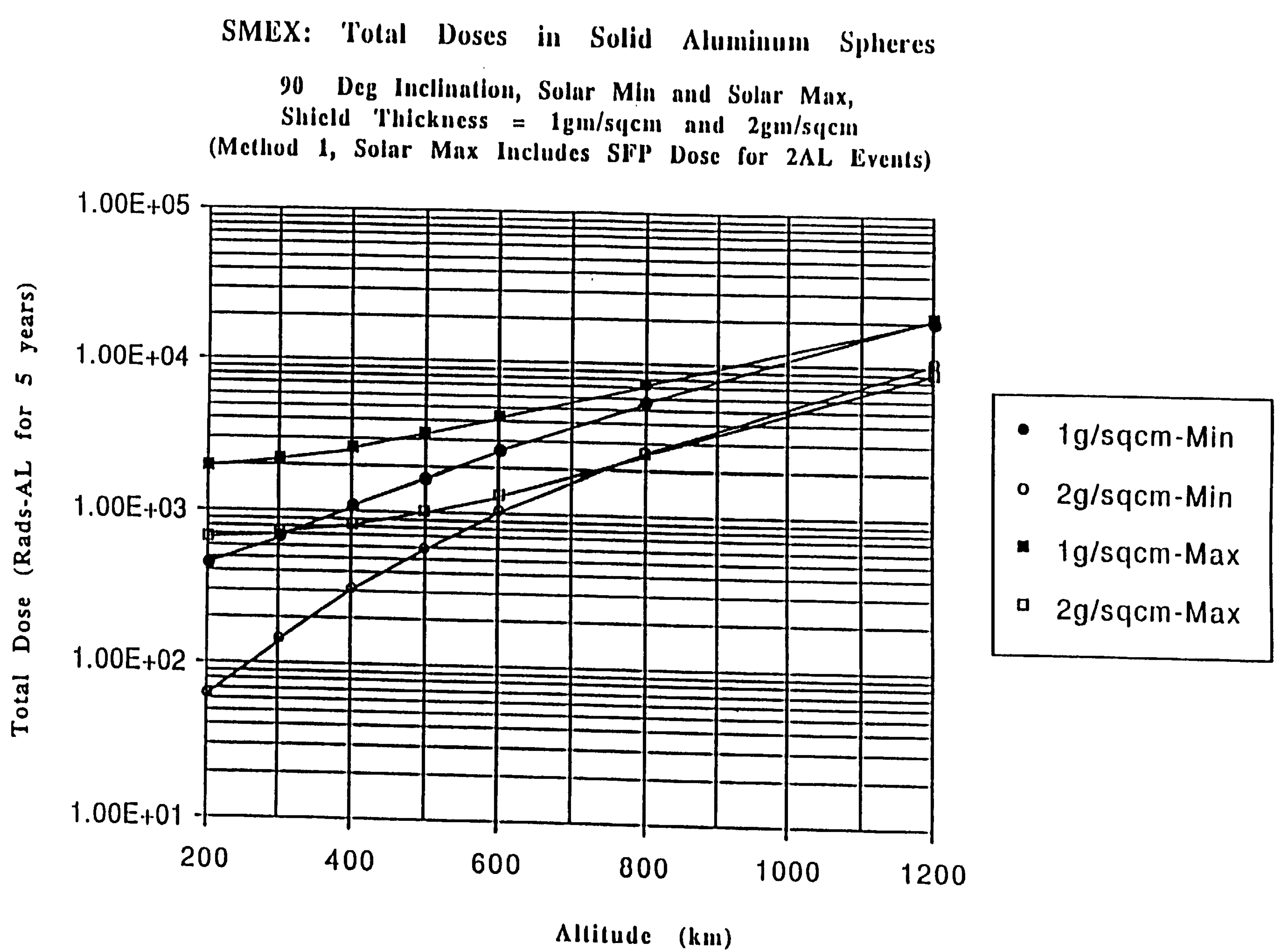
D. ORBIT SELECTION

For the POEMS investigation, a polar orbit is required to gain access to the low energy interplanetary particles. An approximately sun-synchronous orbit is desired for power production and for solar viewing to meet the solar physics objectives. For the mass of the POEMS spacecraft, the Pegasus launch vehicle should be able to achieve an altitude of 800-1000 km.

The orbital trade-off, then, is between orbital lifetime (the higher the better) and radiation, both total dose and instrumental counting rates which will be high in the region of the SAA and the Van Allen belt horns. Keeping the trapped particle dose below 1 k-rad/year limits the acceptable orbits to below altitudes of 800 km.

Operationally, it is necessary to specify the orbital constraints in terms of the viewing conditions for the prime dataset to be obtained. This prime data is electrons above ~20 MeV, and it is necessary that POEMS spend sufficient time at geomagnetic cut-off values less than 20 MV in order to record a statistically meaningful sample of events for analysis. The difficulty is that there is not a one-to-one correspondence between geomagnetic cut-off and magnetic latitude as illustrated in Figure 10 where the width of the band shows the level of ambiguity. Figure 11 shows the calculated cut-off's on a world grid in magnetic latitude versus longitude. Plotted are the portions of the orbit sampled in the calculations performed. The curves correspond to cut-off rigidities of 20 MV, 200 MV, 2 GV and 6 GV to illustrate the dependence. Note that for the lowest rigidity, a magnetic latitude of 78° approximately covers the curve. Thus, the orbit can be specified in terms of the amount of time spent about 78° magnetic latitude. For the nominal one-year mission, this time should be > 22 days.

This time specification, along with the decision to target 600 km as the preferred altitude, allowed the project office to calculate the effects of various orbital inclinations and the Pegasus "spread" in orbital insertion possibilities. A sample of such calculations is shown in Figure 12 for the nominal conditions. A full set of calculations of the time spent within a range of geomagnetic latitudes from the poles, for 12°, 13°, 14°, 15°, and 16°, as a function of orbit inclination, were performed. Note that accumulation time begins at launch plus 30 days, i.e. 12 months from launch means a science data collection period of 11 months. With these specifications, the conclusion was that there would be no problem with the Pegasus vehicle meeting the POEMS science requirements.



SMEX: Total Doses in Solid Aluminum Spheres
90 Deg Inclination, Solar Min and Solar Max,
Shield Thickness = 1gm/sqcm and 2gm/sqcm
(Method 1, Solar Max Includes SFP Dose for 2AL Events)
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
Total Dose (Rads-AL for 5 years)
200
400
600
800
1000
1200
Altitude (km)
1g/sqcm-Min
2g/sqcm-Min
1g/sqcm-Max
2g/sqcm-Max

Figure 9.

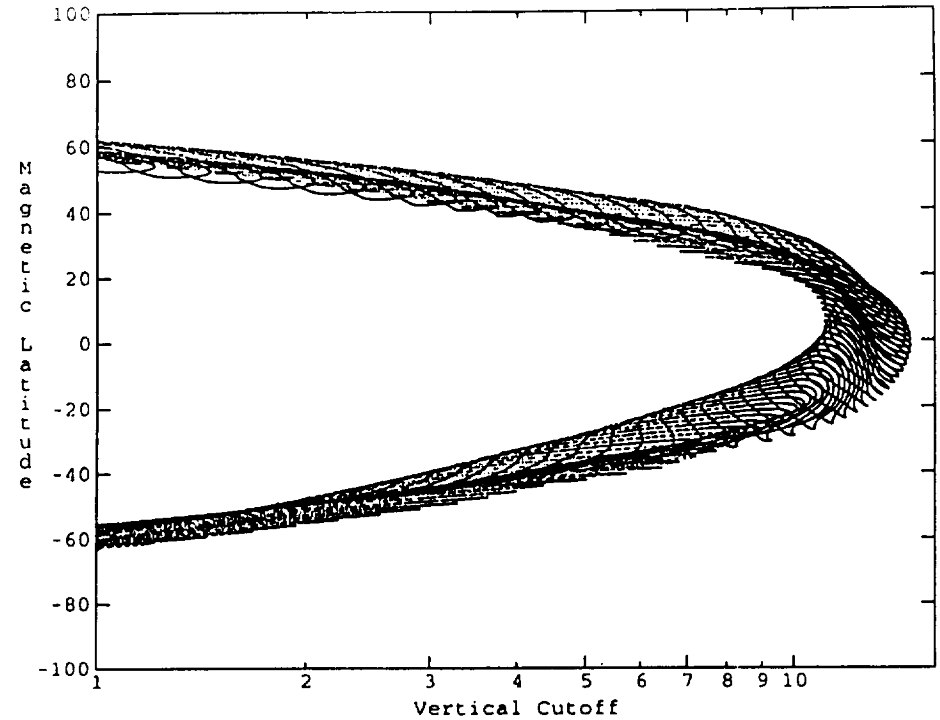


Figure 10. The dependence of the vertical cut-off rigidity on magnetic latitude.

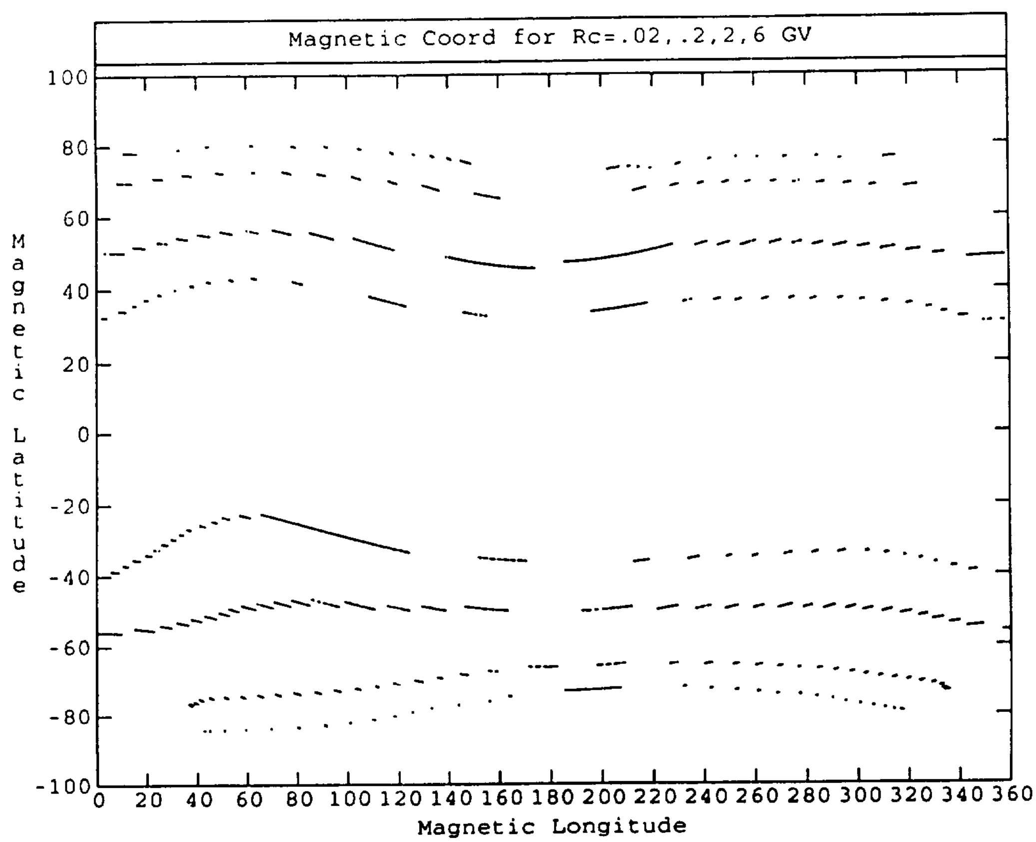


Figure 11. World map in magnetic coordinates showing limits for cut-off rigidities of 20 MV (top and bottom), 200 MV, 2 GV and 6 GV.

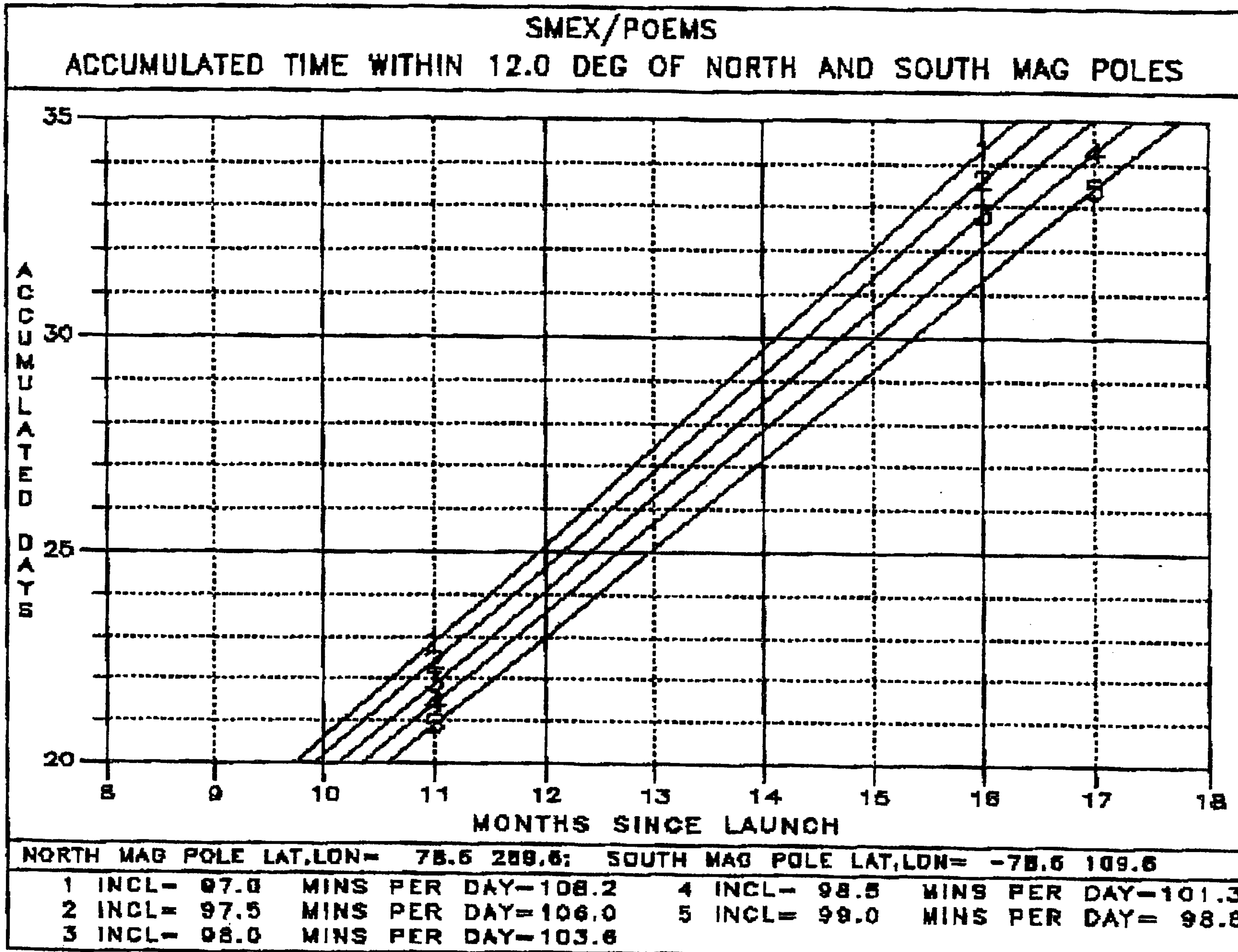


Figure 12. Accumulated time within 12° of the magnetic poles as a function of orbital inclination (from SMEX project office courtesy C. Petruzzo).

E. RADIATION SPECIFICATION

For the 600 km orbit we expect a dose of about 0.5 k-rad/year from only the trapped particle populations (assuming 1 g/cm^2 shielding). This will be augmented by GCR and solar energetic particle events. This level is, however, low enough so that no special radiation hardness specification needs to be applied to the parts used in the POEMS instruments or the spacecraft. Minimal shielding will be required for any components sensitive at the 20 k-rad level. This level should not be exceeded, except if there is a very large solar flare - - probability is less than 10%. For guidance, Figure 13 (from Stassinopoulas and Barth, 1989) can be used as the radiation specification focusing upon the 800 km, solar minimum curve. For particle problems or sensitivities, special analysis will be necessary. No planned POEMS parts appear to require such analysis.

IV. DATA RATES AND TELEMETRY

The POEMS data will be dominated by the trapped components, including return albedo particles. Since the EES records events down to ~200 keV, we expect to have to analyze the datastream in terms of the McIlwain coordinates, B and L. For the trapped protons and electrons, we employ the technique of the Short Orbital Flux Integration Program (SOFIP). The nominal orbit, along with the current IGRF magnetic field model, is used to determine B, L values. These are then input to AE6MAX (or AEI7HI) and AP8MAC, the NSSDC trapped particle subroutines for electrons and protons respectively. This gives an omni-directional integral flux (number/cm^2 - s) above a particle energy threshold for each step along the orbit. Figure 14 shows the spectra of the trapped electrons and protons. The models show no electrons above ~7 MeV, but this is probably an artifact of previous datasets. One of the POEMS secondary objectives is to look for high energy electrons in the trapped population. The protons show a relatively hard spectrum, extending well above 100 MeV. These are observed principally in the region of the South Atlantic Anomaly (SAA) and, for E > 100 MeV, can have a flux as large as $10^3/cm^2$-s).

The electrons are observed both in the SAA and at high latitudes in the 'horns' of the Van Allen belts as illustrated in Figure 15 for four energy ranges > 0.1 MeV, > 0.5 MeV, > 3.0 MeV and > 5.0 MeV. (The darkness of the plot is an approximate indicator of the intensity.) For > 500 keV, the peak intensity is $10^5/cm^2$-s, while for > 5 MeV it is down to $10^3/cm^2$-s. In the POEMS datastream, these particles will appear as spikes of minutes duration occurring several times per orbit.

Balloon studies over the past three decades have revealed the presence of return albedo electrons, observed because they appear at energies below the local geomagnetic cutoff and thus must be pseudo-trapped. This albedo component can be many times more intense than the GCR electrons. This implies that the POEMS analysis will have to focus on obtaining accurate geomagnetic cut-off values for each event observed.

For our evaluation of data rates, we employed balloon measurements to derive an albedo electron energy spectrum as shown in the top part of Figure 16, compared to the GCR electron and proton spectra. It was assumed that the albedo particles exist for all energies below the geomagnetic cut-off, as illustrated in the lower portion of Figure 16. (No return albedo protons were included.)

Putting the trapped, albedo and GCR components together, we can predict the particle flux as a function of time around the SMEX orbit. (For this the omni-directional trapped flux was divided by 4π and an observational efficiency of 10% was assumed.)

SMEX: Total Doses in Solid Aluminum Spheres

90 Deg Inclination, Solar Min and Solar Max, 800 and 1200 km
(Method 1, Solar Max Includes SFP Dose for 2AL Events)

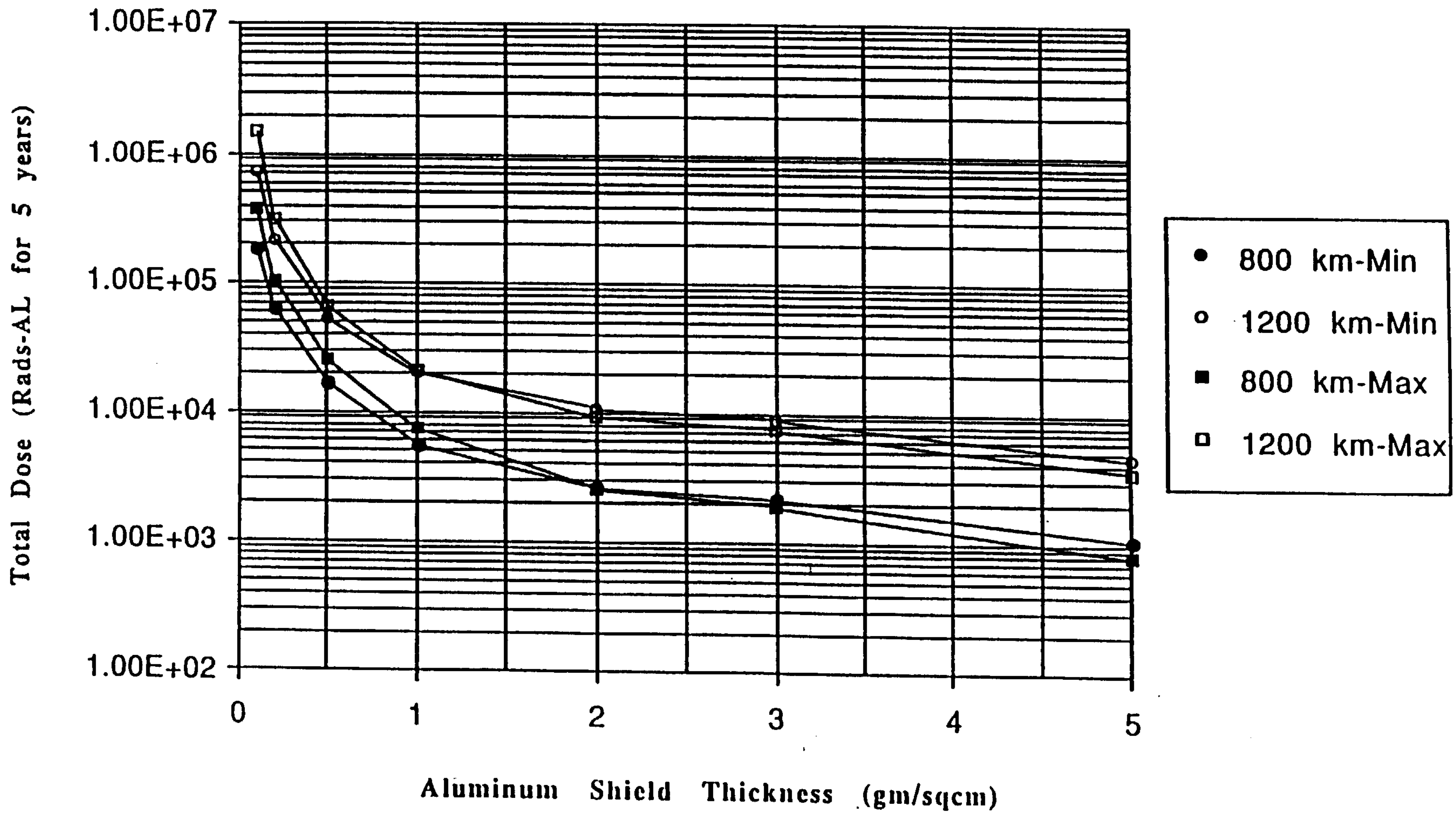


Figure 13.

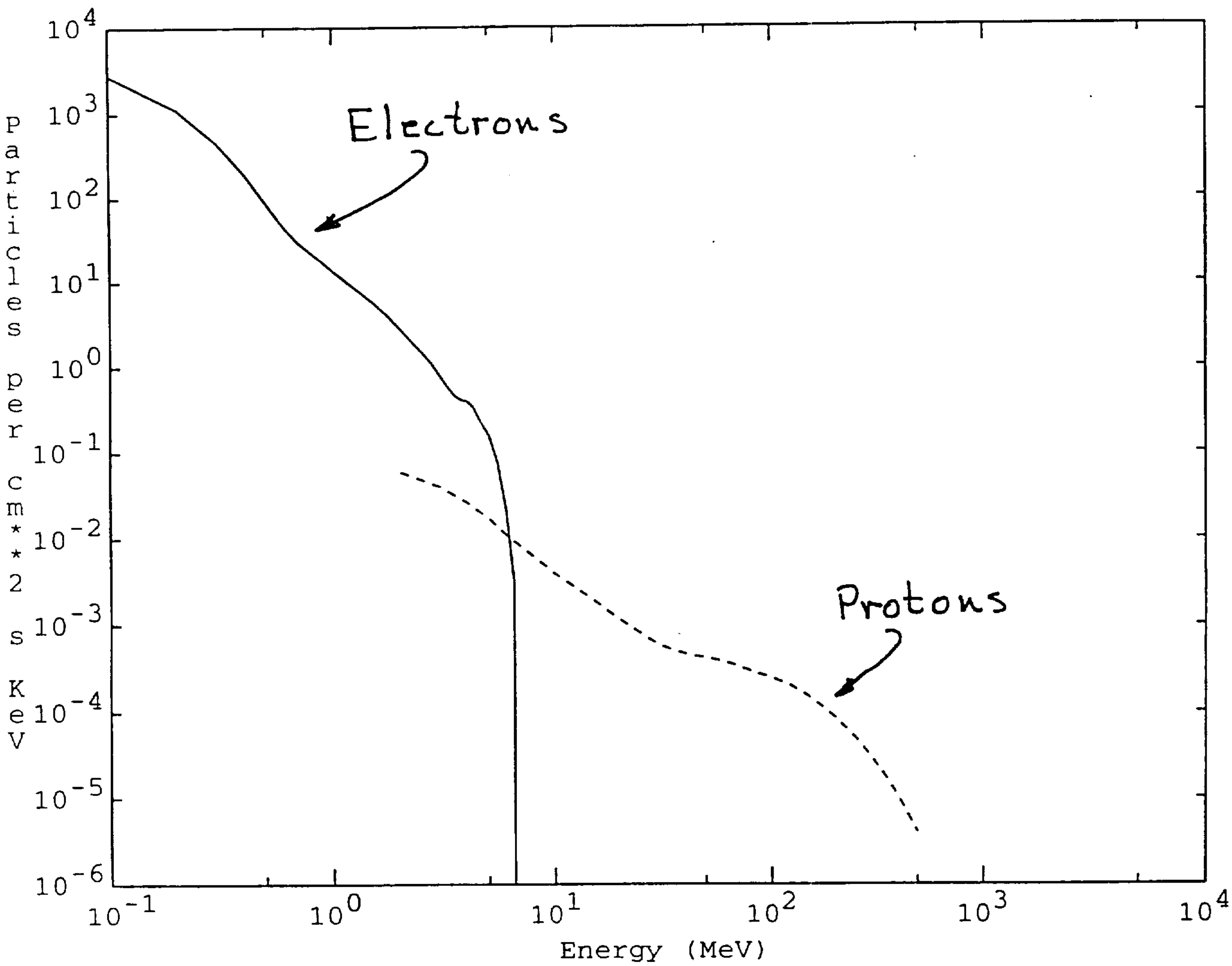


Figure 14. Energy Spectrum of the trapped protons and electrons as given by the models.

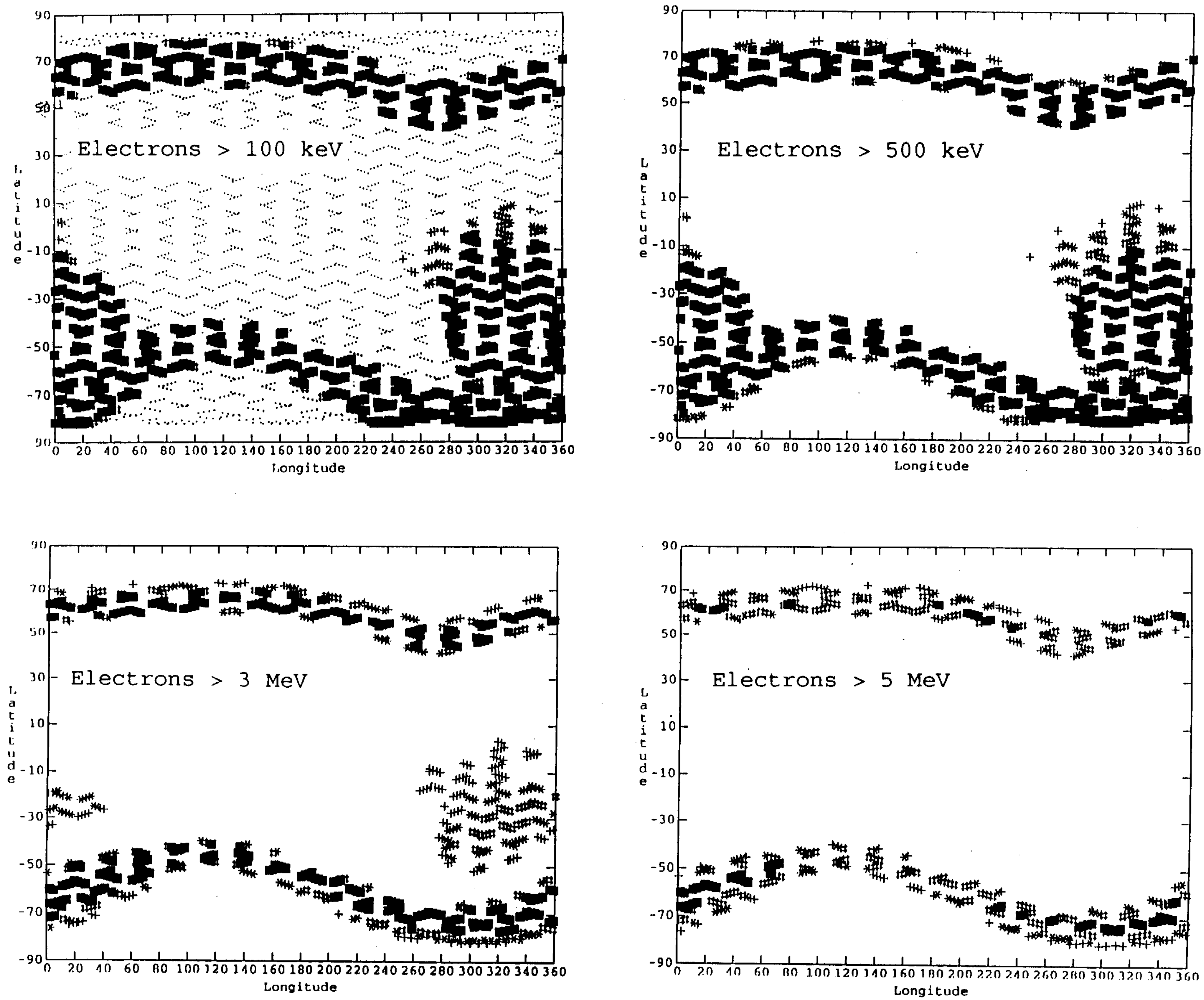
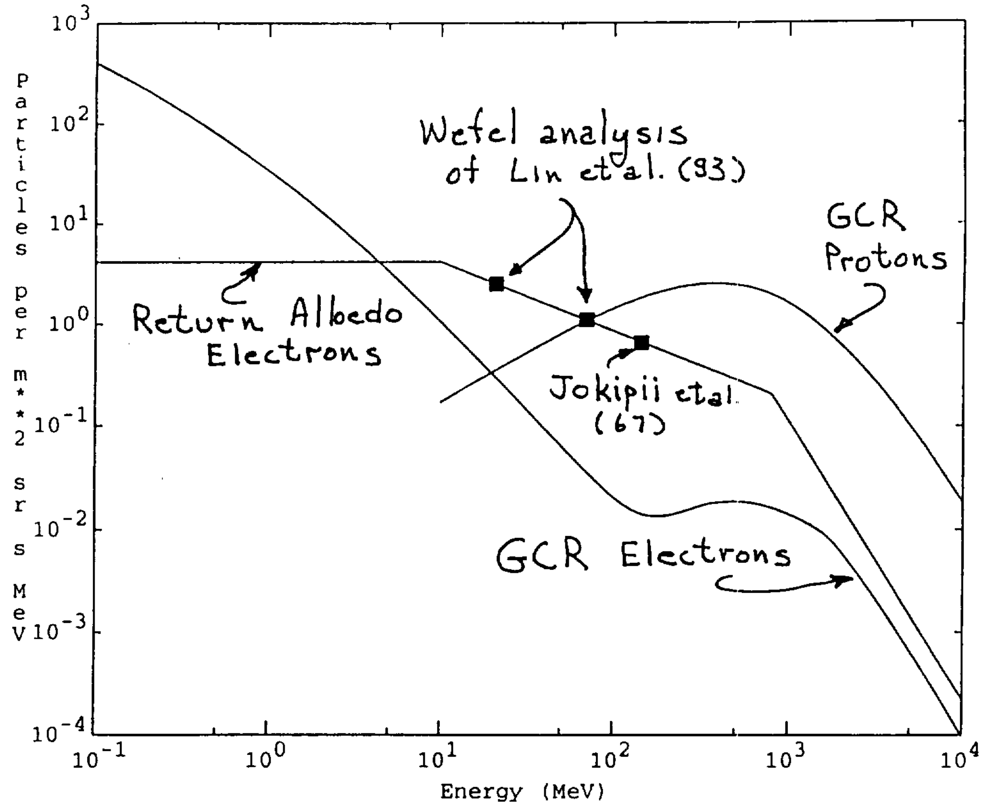


Figure 15. World plots in latitude and longitude of the trapped electrons for energies > 0.1, > 0.5, > 3.0 and > 5.0 MeV. The darkness of the points is related approximately to the intensity of the radiation.



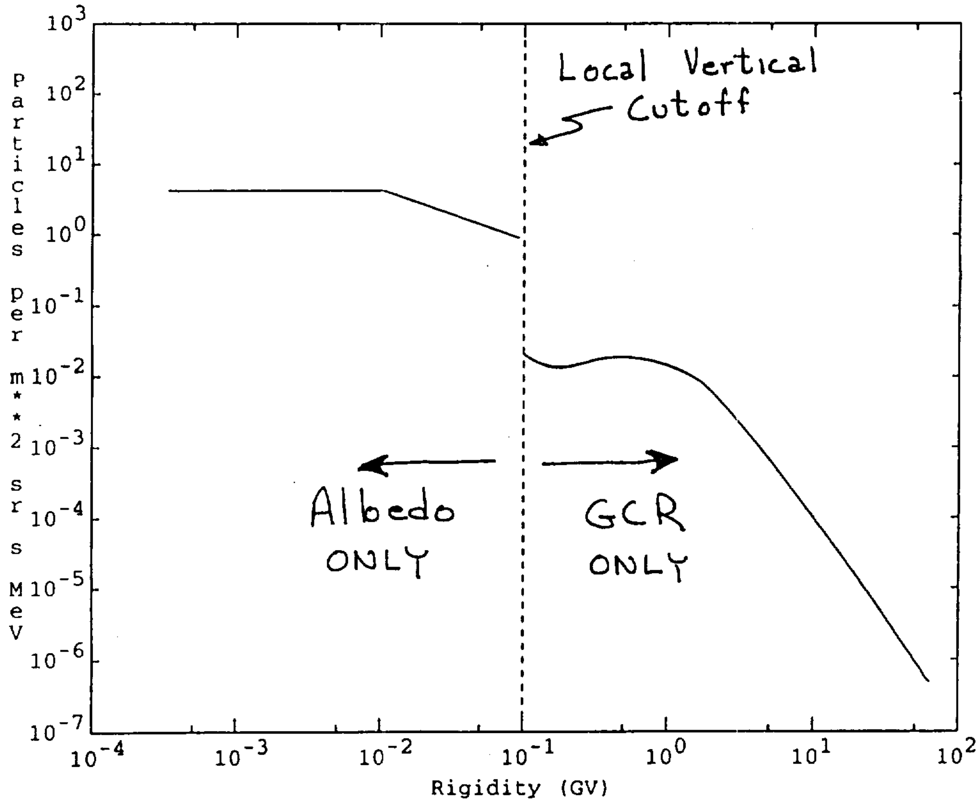


Figure 16. Assumed energy spectrum of the albedo electrons compared to the GCR proton and electron spectra (top). Schematic illustration of the assumed rigidity dependence of the albedo and GCR electrons (bottom).

Figure 17 shows the result for > 100 keV electrons (top) and > 20 MeV protons (bottom). The GCR intensity is shown as the solid curve with the trapped particles as the short dash curve. For protons there is no albedo, and the trapped particles are clearly observed as the spikes corresponding to SAA passes. Similar spikes are evident for the elections from both the SAA and the outer belt. However, in between the spikes the flux is dominated by the albedo. The GCR component can be observed only in the short time periods between the dashed lines, i.e. near the geomagnetic poles. The GCR component is at a level of a few times 10^{-2} particles/cm^2-sr-s while the trapped electron spikes are at least five orders of magnitude larger.

The situation improves for higher energies as shown in Figure 18 for > 20 MeV electrons and > 200 MeV protons. The trapped population is absent for the electrons, but the albedo component still dominates, except over the poles. The trapped protons can still be seen but do not dominate the overall counting rate.

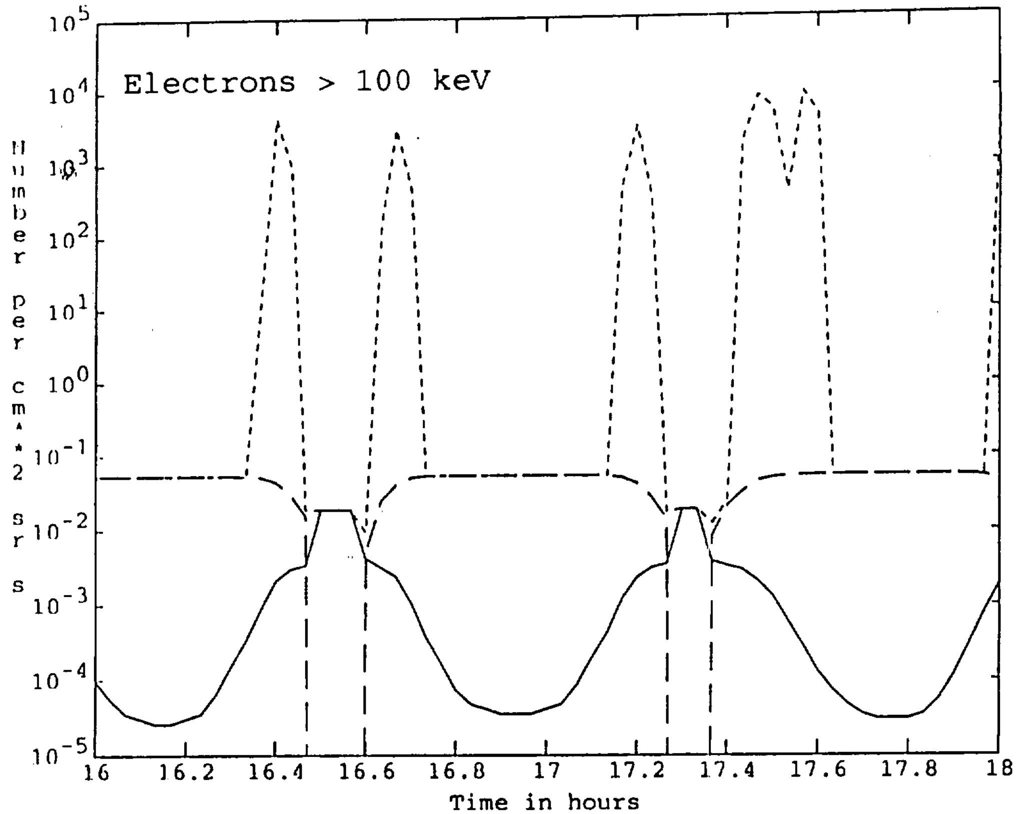
Looking at one days data, Table 2 shows the total expected counts integrated above the given energy thresholds. For the lower energies, the trapped (and albedo) component dominates, and it will only be possible to identify the different components (and pull out the GCR events) by utilizing the location of the spacecraft at the time each particle is observed. This is why POEMS requires accurate orbit/altitude information, post flight not real time, for the scientific analysis.

Looking at the MS only, there will be ~10^5 particles per day which could be pulse height analyzed. At an assumed 75 bytes per event, this corresponds to a raw data rate of about 11 M-bytes per day. The EES will observe even larger fluxes, so it has the potential to generate 20+ M-bytes per day. This poses a problem which must be solved by not pulse height analyzing every event and by some on-board processing of the raw datastream.

Referring to Figures 17 and 18, if data is taken only within the regions defined as free from albedo and trapped particles then the number of events to be extracted from the raw data stream is given in Table 3. Here the problem is extracting the electron signal from the much more abundant protons. Requiring that the gas Cherenkov counter show a signal can discriminate against the protons with an efficiency of 10^3-10^4 while losing less than 1% of the electrons. This will have to be the main MS coincidence mode.

For the EES, it will be impossible to pulse height analyze all of the events. Rather, histograms in energy will be accumulated every minute for different trigger conditions, and these will be the main data. Full pulse height analysis will be performed and transmitted for only a small sample of the events.

Overall then, including pulse height analysis, histograms, engineering and housekeeping data, count rate data and calibration data, the POEMS experiment requires a downlink rate of 10-30 M-bytes per day. Less than this rate will require significant on-board data compression by the spacecraft computer system.



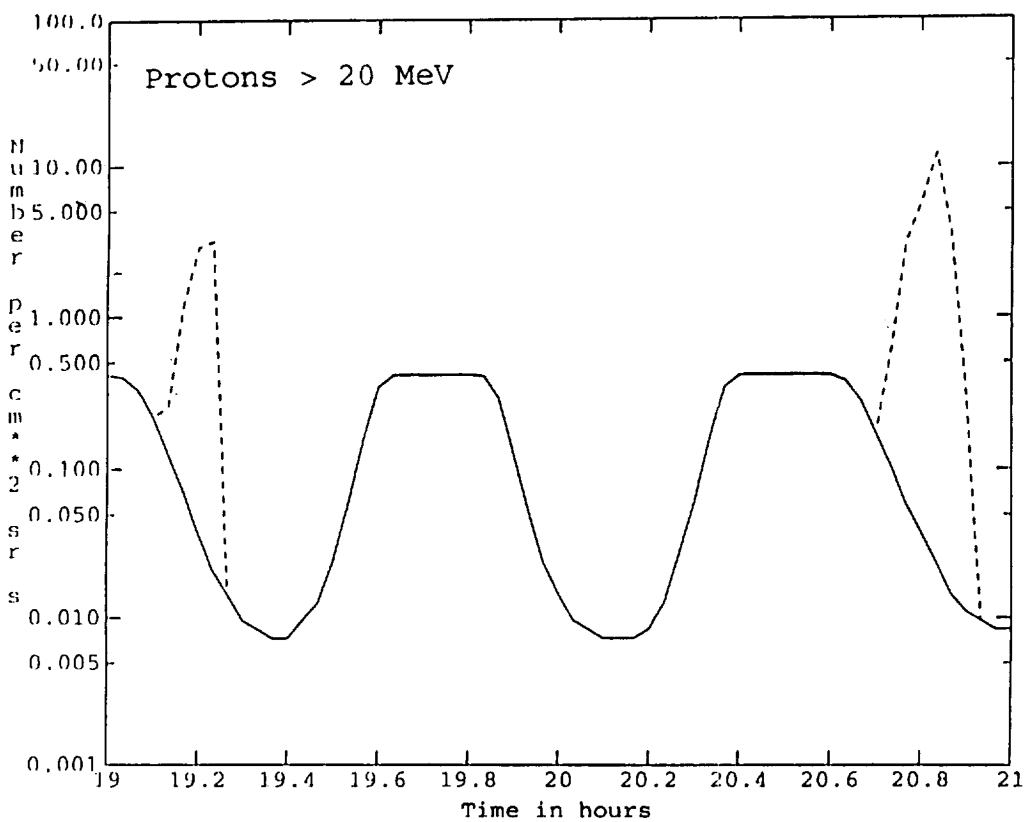
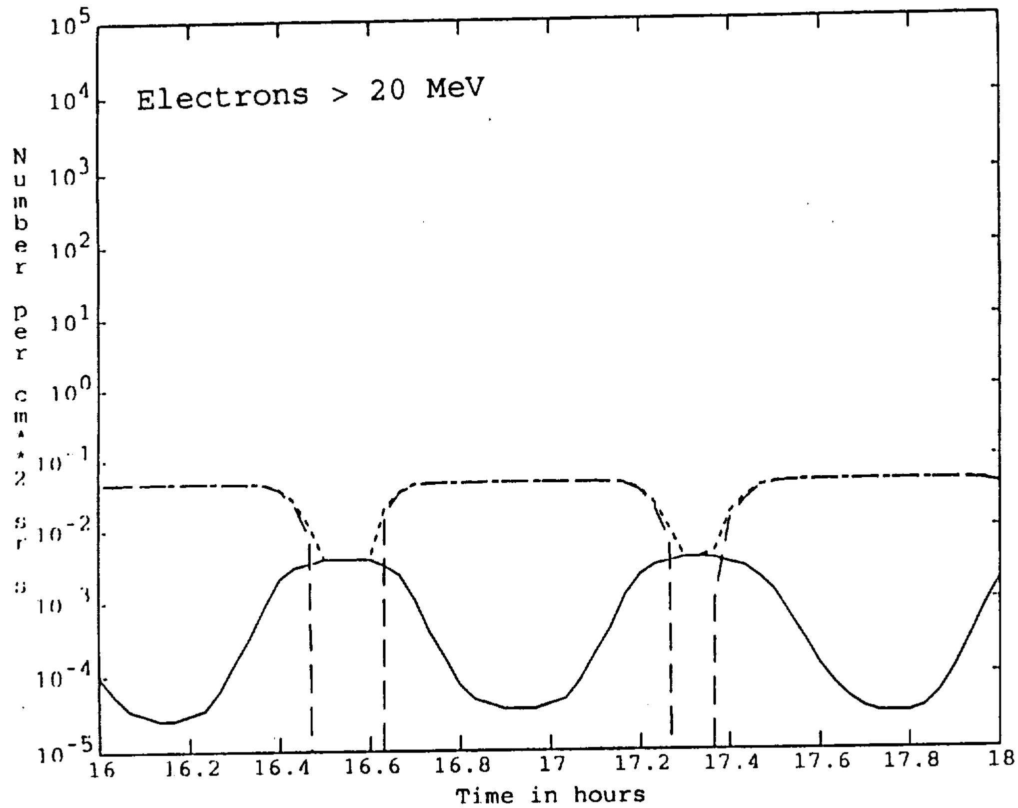


Figure 17. Combined flux of all components as a function of time in a 600 km orbit for electrons > 100 keV (top) and protons > 20 MeV (bottom). The GCR is represented by the solid curves; trapped particles by the short-dash curve; albedo electrons are shown as the long-dash curve.



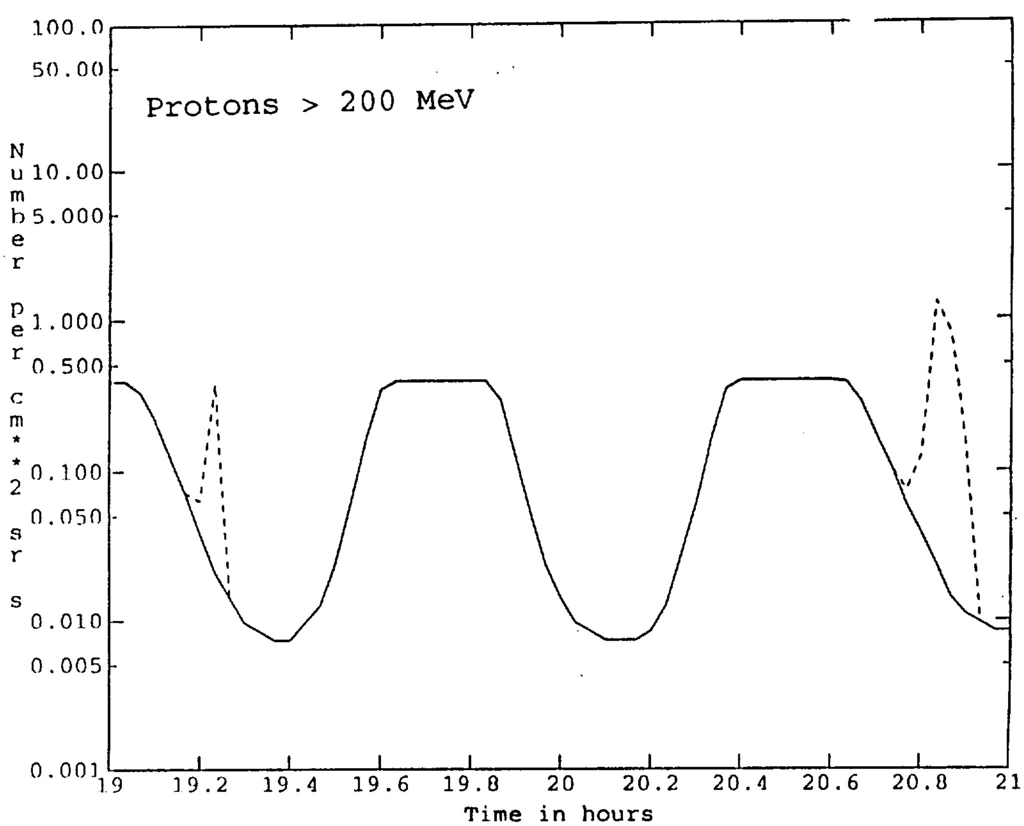


Figure 18. Same as figure 17 except for electrons > 20 MeV (top) and protons > 200 MeV (bottom).

TABLE 2. TOTAL ELECTRON AND PROTON COUNTS

Electron Counts

Energy Range (MeV)	GCR	Albedo	Trapped	TOTAL
> 0.1	451	9016	5.7×10^8	5.7×10^8
> 5.0	293	8601	1.5×10^5	1.6×10^5
> 20.0	270	7535	0	7805
> 70.0	260	5991	0	6251
> 200.0	252	4249	0	4501
> 1000.0	174	828	0	1002

Proton Counts

Energy Range (MeV)	GCR	Albedo	Trapped	TOTAL
> 20.0	38367	0	97217	135587
> 70.0	38201	0	55752	93954
> 200.0	36912	0	14370	51283
> 500.0	31824	0	701	32525
> 1000.0	23623	0	0	23623

TABLE 3. COUNTS DURING "PURE" GCR VIEWING CONDITIONS

Electrons

Energy Range (MeV)	Live Time (Percent)	GCR Counts per day
> 0.1	6.4	233
> 5.0	6.7	78
> 20.0	8.0	68
> 70.0	12.3	89
> 200.0	18.5	125
> 1000.0	33.6	131

Proton

Energy Range (MeV)	Live Time (Percent)	GCR Counts per day
> 20.0	91.7	37700
> 70.0	92.9	37800
> 200.0	94.9	36700
> 500.0	97.6	31700
> 1000.0	100.0	23600

V. HELIOSPHERIC MODULATION

The original POEMS experiment on EOS would have been active for 10+ years, covering essentially a full 11 year solar cycle, including the reversal in polarity of the Sun's magnetic field. It is believed that the field polarity controls the access routes of GCR into the heliosphere, with positive particles having easier access during one polarity while negative particles have preferential access during the opposite polarity. This heliospheric modulation is, however, a function of rigidity so that accurate measurements must be made on particles of the same mass and velocity, but of opposite charge. Positrons and electrons are the only accessible particle pair that meets this requirement.

Since the SMEX mission for POEMS will be nominally of one year's duration, we have looked at what information could be available on heliospheric modulation from this single (in time) sample. Assuming only secondary positrons in the interstellar flux, we unfolded the Protheroe positron to total electron ratio to produce an energy spectrum of positron's in local interstellar space. In addition, we prepared a total electron spectrum outside the heliosphere.

Jokipii and co-workers in Arizona have developed a model of the heliospheric termination shock and the heliospheric modulation which contains, explicitly, the polarity of the solar magnetic field. They have used this to investigate particle access and the high solar latitude behavior of energetic particles.

Jokipii used our local interstellar spectra as input to his model and predicted the spectra of electrons and positrons at Earth for the two signs of the solar magnetic field $A_{positive}$ and $A_{negative}$. These were then used with the MS geometry factor and expected live time to predict the data to be obtained. The results are shown, for one 27 day solar rotation period, in Figures 19 and 20 and are fascinating.

Figure 20 has peaked up the secondaries relative to our previous plots, and this is interpreted as favoring e^+ and suppressing e^-, with the effects a function of energy. Figure 19 shows, almost, the inverse shape as a function of energy. This is most likely inhibiting e^+ and favoring e^-, again as a function of energy. Note that the cross-over point is at ~70 MeV. Whether this point is significant or not, we don't know. Note also that above ~200 MeV the POEMS MS would be able to separate the different curves.

What is important here is the different <u>shape</u> of the ratio plot for $A_{negative}$ and $A_{positive}$. While we probably cannot predict the absolute fluxes of e^+ and e^- with any certainty, the shape of the interstellar energy spectra is probably better known. Thus, by measuring the shape of the ratio as a function of energy, we can obtain information on the models being used here. Since 1998 will be A positive, we will be able to look for this shape effect, say something about the modulation, and, perhaps, explain the previous balloon data in terms of charge sign dependent heliospheric modulation.

VI. DATA PROCESSING PLAN

The general data flow through the POEMS experiment ground system is illustrated in Figure 21. Data telemetered from the spacecraft are received by the appropriate ground stations and transferred to the SMEX Mission Operations Center (SMEX MOC). The SMEX MOC provides the interface between the POEMS spacecraft and the POEMS fight and data processing operations.

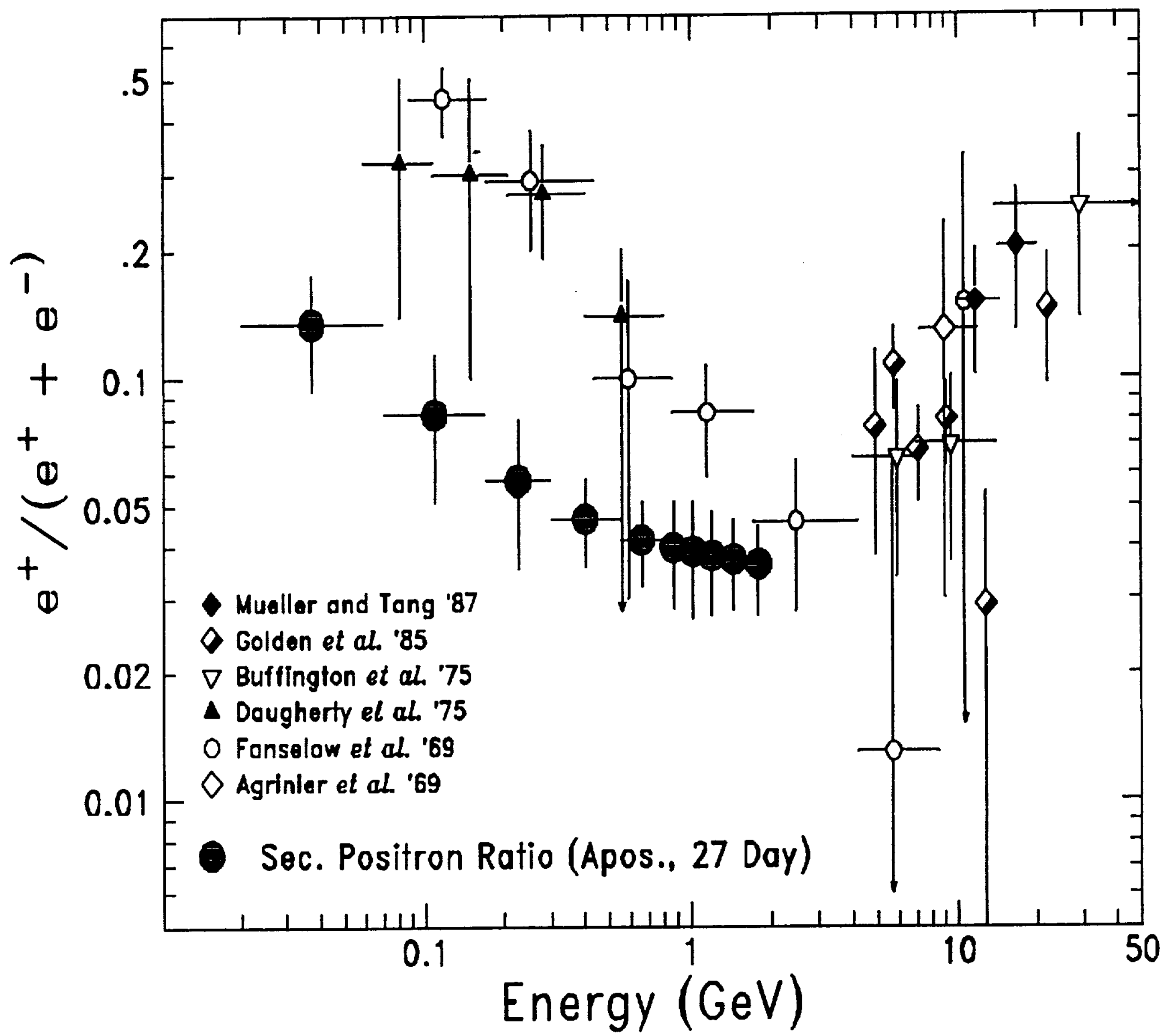


Figure 19. Positron to total electron ratio for one 27-day solar rotation period for A positive conditions, compared to previous balloon data.

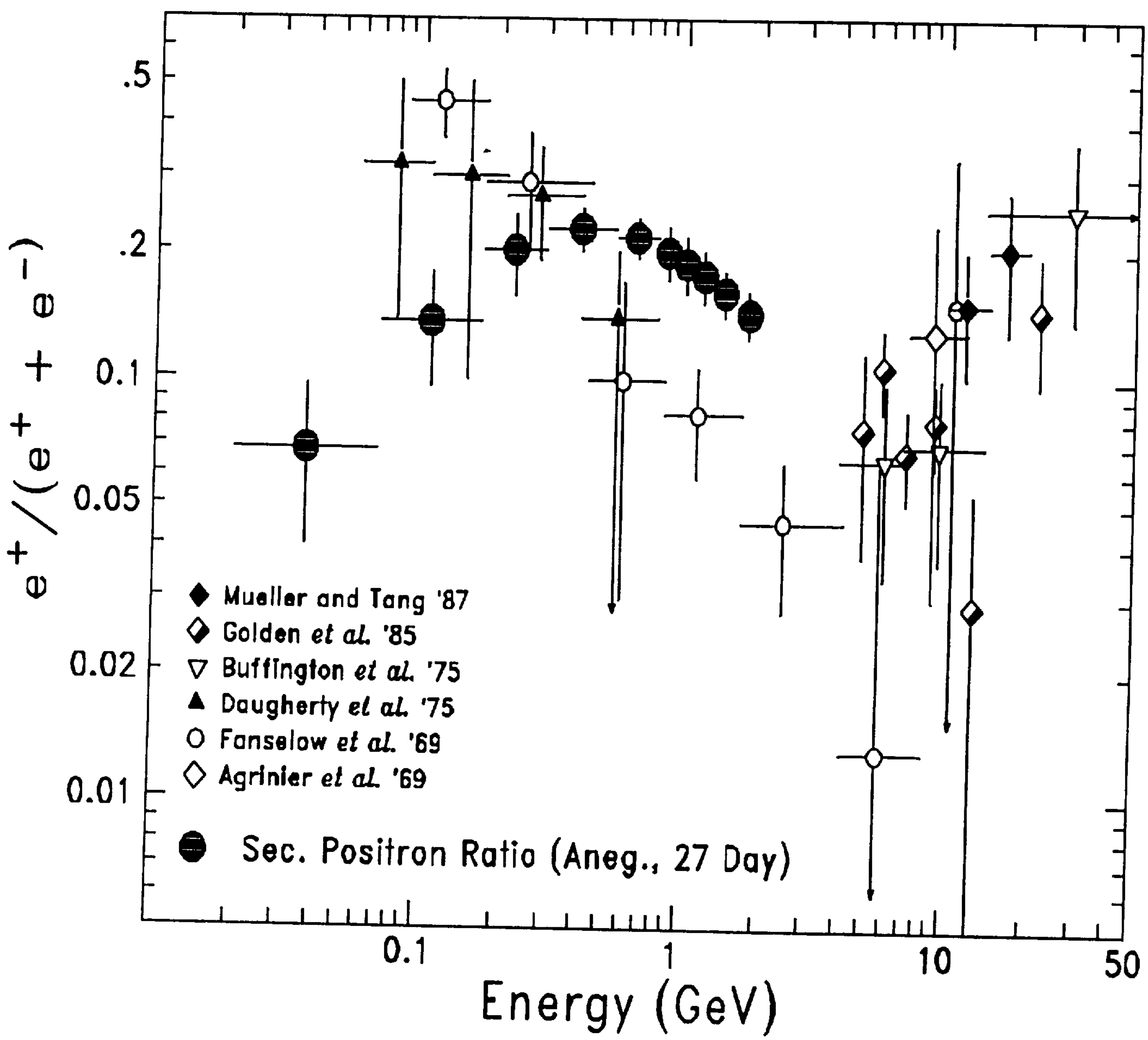


Figure 20. Same as Fig. 1 except for A negative conditions.

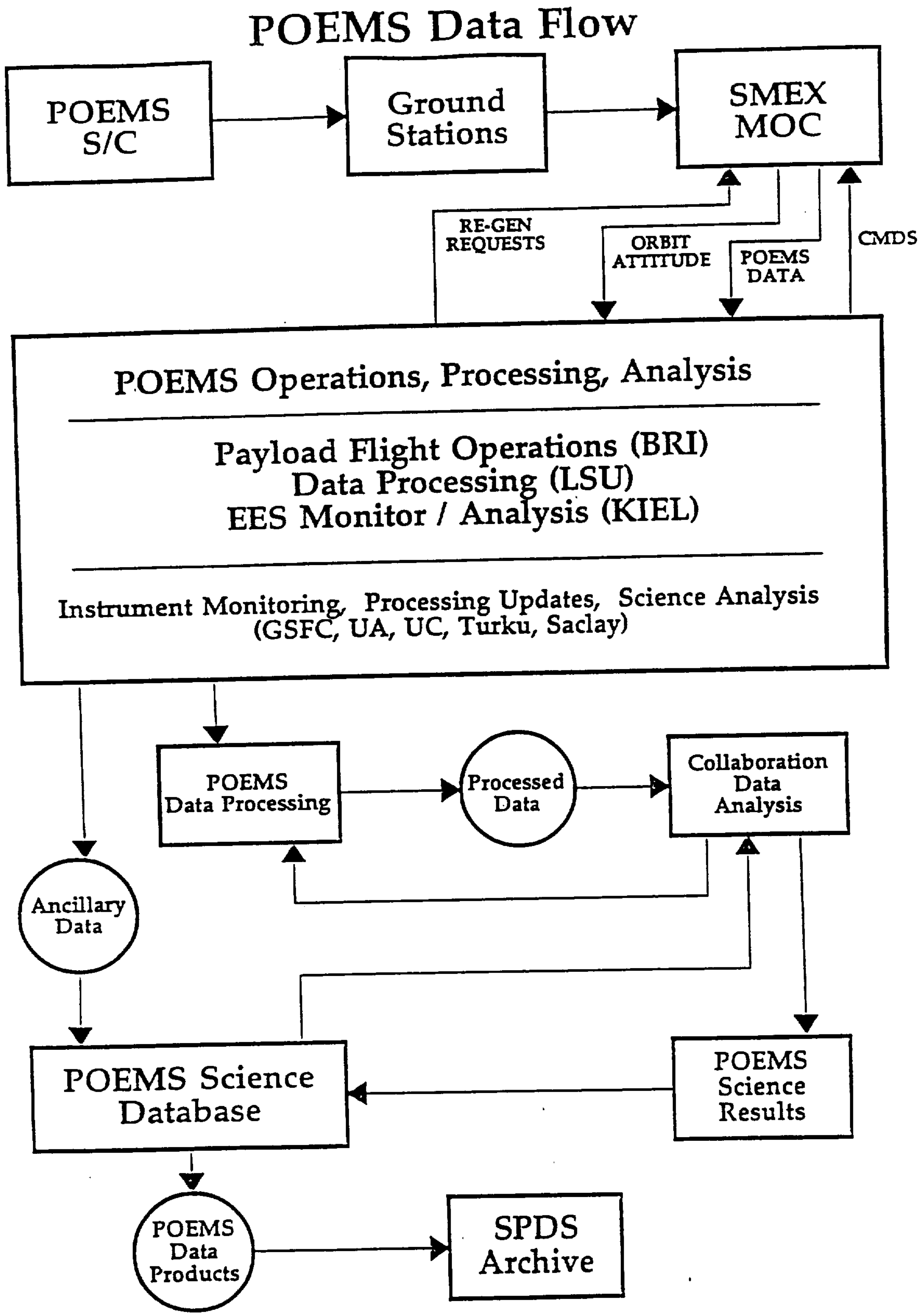


Figure 21. Data flow in the POEMS/SMEX experiment ground system.

POEMS flight operations are centered at Bartol Research Institute (BRI) which receives daily quicklook data, monitors the health and operation of the experiment and forwards commands for uplink to the spacecraft. BRI is assisted in the real time monitoring of the experiment by the University of Kiel (Kiel) and the remaining POEMS collaborators, as needed. The POEMS data processing operation is centered at Louisiana State University (LSU) which receives the daily data download, including orbit / attitude information, processes and distributes this data, maintains an online science analysis database, and communicates with the SMEX MOC on issues concerning the data processing (e.g. data re-generation requests). Processing of the POEMS Extended Energy Sensor (EES) data will be performed in conjunction with Kiel. All POEMS collaborators will provide data processing subroutines and calibration files and/or will be involved in the science analysis.

The raw POEMS data (Level 0) is processed to higher levels (1, 2 and 3) where at each stage increasingly sophisticated data conversion and selection algorithms are applied. All high level data are distributed to the POEMS team and analyzed to provide updates to the processing routines and calibration files, as well as science results such as the electron and positron energy spectra. These are combined with ancillary solar, geomagnetic and interplanetary data in the POEMS Science Database and used during science analysis and interpretation. Resulting data products along with the full POEMS dataset will be submitted to the Space Physics Data System/NSSDC for archiving and public access.

B. DATA PROCESSING IMPLEMENTATION

Implementation of the POEMS ground data processing system will take place primarily at LSU. Elements of the processing software will draw upon routines and calibration files developed by the POEMS collaborators for the instrument GSE. To enable these codes and data to be easily integrated into the overall software and to provide uniform access to the processed data, we will adopt a set of format and documentation standards (Section 1). A multiple level processing scheme will be implemented where each level builds upon the previous stage (Section 2). Such a scheme provides flexibility in selecting data subsets for analysis, isolates and minimizes any necessary re-processing, and simplifies the processing software implementation into discrete modules. All high level processed data will be distributed to all POEMS collaborators on a regular basis using CD/R media (Section 3). The CD/R media was chosen because it is random access, has an interoperable format, and is expected to have a lifetime in excess of 30 years. Thus, the data distribution will double as the POEMS internal archive. The data processing hardware is moderately sized and reflects the expected low data rate from the POEMS instrument (Section 4). Finally, the timeline for implementing the ground data processing system (Section 5) provides for a phased approach with all essential components completed by the MOR, and the system fully operational six months prior to launch.

1. Standards

Collaborators in the POEMS experiment use a wide variety of computer platforms and data analysis tools. Thus, instead of adopting one particular platform we intend to establish a set of data and software standards which will enhance interoperability across the collaboration. These standards would apply to any data or software that is to be used across the collaboration, but internal data handling and analysis will be at the discretion of the individual institutions.

These standards will be negotiated and established at the beginning of the Design phase and a "Standards Document" will be distributed to all institutions. These standards will be divided into 1) Code, 2) Documentation, and 3) Data, with Data further divided into

3a) Flight data, 3b) Detector parameters, 3c) POEMS Results, and 3d) Ancillary data. At a minimum we expect the following standards to be adopted:

1. Source code is to be written in a high level language such as FORTRAN or ANSI-C.

2. Code must be modularized where each module performs a single function.

3. Code documentation must be provided which describes the routines function, operation and interface variables.

4. System specific routines must be minimized and embedded within a FORTRAN or C subroutine.

5. Windowing operations will use standard X11/R5 or Motif widget calls only.

6. Flight data will be distributed in a standard format (TBD) such as CDF, which is widely accepted, is fully documented and has access / manipulation software already developed for multiple platforms.

7. Detector parameters and POEMS results will be passed as formatted ASCII data files with associated documentation describing the file contents.

By refining, expanding and adopting such standards we expect to simplify the interface between institutions and establish guidelines for developing the ground data processing software.

2. Data Processing Levels

The POEMS data processing begins with generating a Level 0 dataset which is, in essence, the datastream sent by the EES and MS to the spacecraft DPU. The next stage of processing generates Level 1 which is still "raw" data but has orbit / attitude information (obtained from the SMEX MOC) added as well as being converted to a standard format and split into category (e.g. rate, housekeeping, events) subsets. Level 1 processing applies the detector calibrations, converting "channels" to "science units", and generating the Level 2 data volumes. Finally, during Level 2 processing events are selected, the particle charge, mass and energy are determined and the Level 3 data set is generated. The Level 3 data is used in conjunction with ancillary solar, geomagnetic and interplanetary data for the POEMS science analysis and interpretation.

The steps leading to the POEMS Level 0 data are shown in Figure 22. POEMS flight data and Attitude / Orbit information is received at LSU and logged. Auxiliary information such as spacecraft / ACS housekeeping data (TBD) and spacecraft data filtering parameters are also acquired for later processing. The POEMS flight data is unpacked from the CCSDS encapsulation and checked for data integrity, time intervals and data gaps. If these initial checks fail then a request for a re-generated data volume is sent to the SMEX MOC. The verified data is then merged with previously processed data, filling in data gaps and assuring that the data is time ordered. This Level 0 data is archived at LSU but will be distributed only on request.

The Level 0 data is next processed to Level 1 as shown in Figure 23. First all packets are identified and distributed to individual data files according to category (i.e. MS events, EES housekeeping, MS calibration, etc.). These file are read by a Data Formatter which 1) decompresses the compact Level 0 format, 2) merges EES, MS and S/C

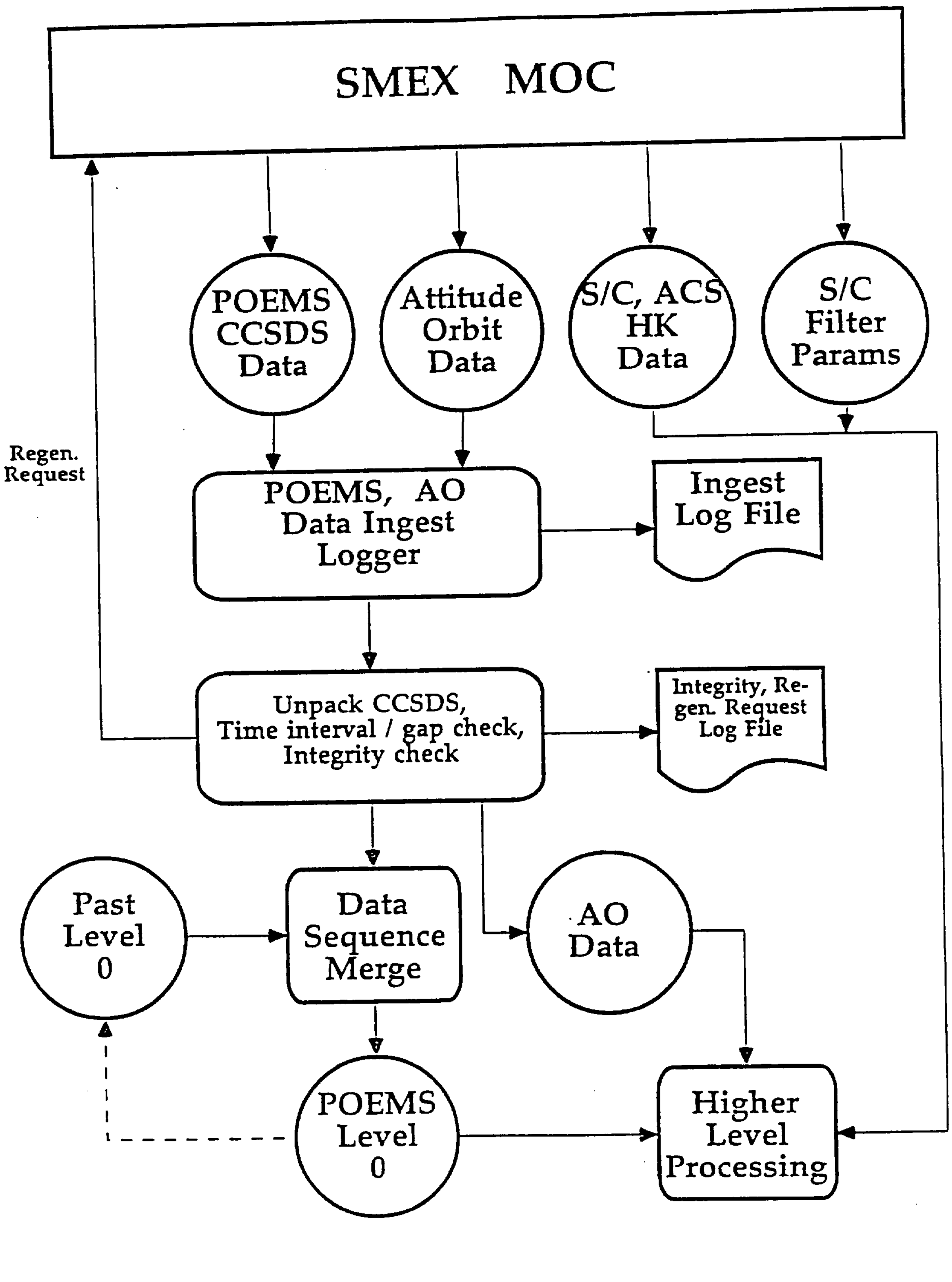


Figure 22. Production of Level-0 data.

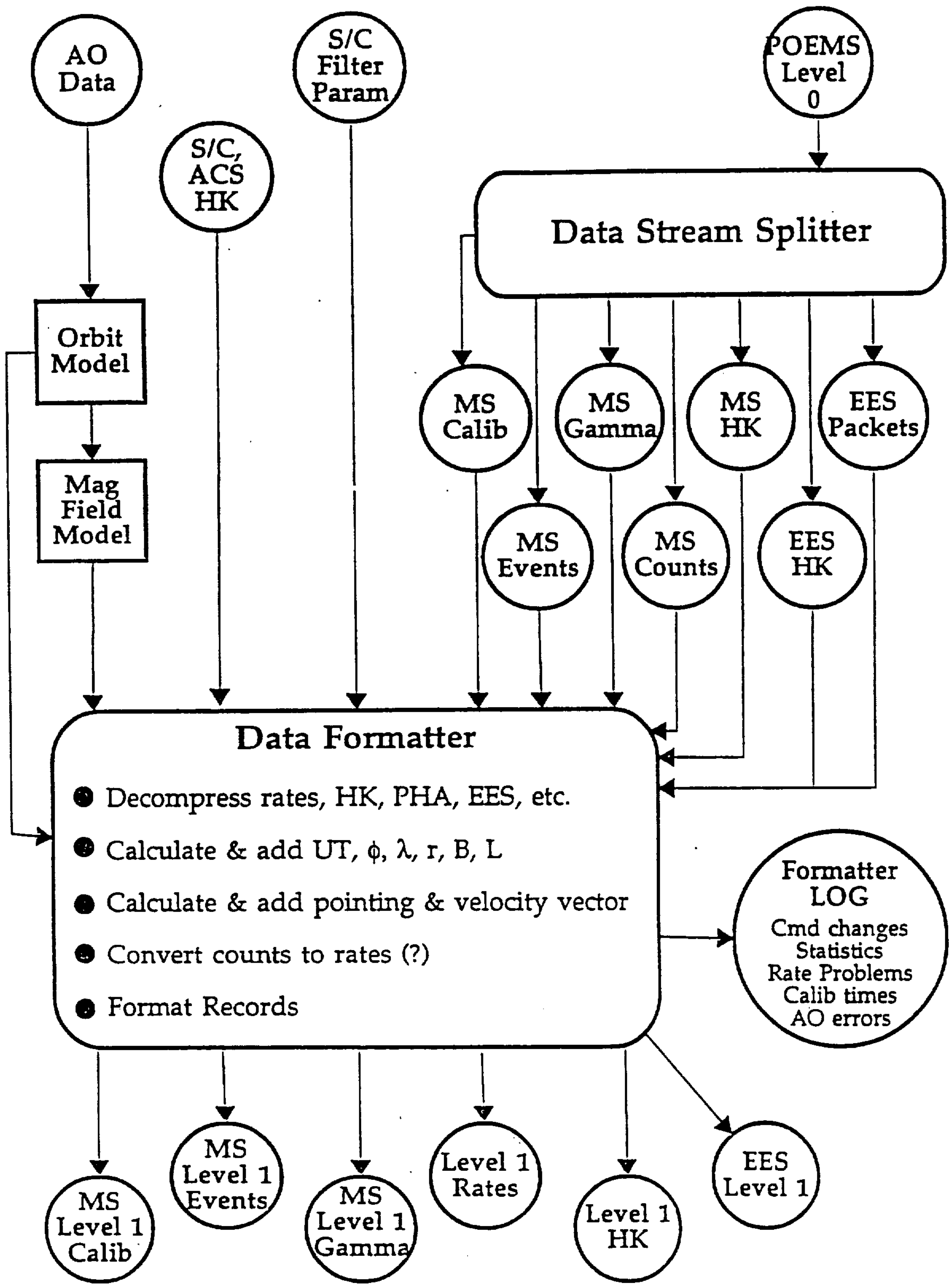


Figure 23. Level-0 processing of the POEMS data to form the Level-1 datasets.

housekeeping information, 3) converts counts to counts per second, 4) converts the internal clock time to UT, 5) uses the attitude / orbit data along with an orbit and magnetic field model to interpolate and add the spacecraft position, magnetic field B and L coordinates and pointing vector to each event and rate record, 6) adds auxiliary flags or data such as the spacecraft filtering parameters, and 7) converts the data records to a standard format. In addition, the formatter will generate a log file that will track items such as instrument command changes, calibration time periods, statistics on the category and number of records processed and any errors or problems encountered during processing. At least seven different Level 1 datasets will be generated including MS calibration data, MS particle Events, MS gamma ray events, Rates data, EES calibration data, Housekeeping data and EES data/spectra.

To monitor the radiation environment as well as the instrument health and long term stability, a variety of time plots will be generated from the Level 1 Rates, Housekeeping, EES and Calibration data as shown in Figure 24. In addition, the in-flight calibration data is processed, using routines supplied by Saclay (CEA) and Kiel, to obtain results used later in correcting the instrument data.

Level 1 processing, where detector calibrations are applied, is illustrated in Figure 25. As the detector calibrations may be a function of environmental conditions such as temperature or particle intensity, the Level 1 Rate and Housekeeping data is filtered to identify time periods where the calibrations may not apply and to generate environment parameters to be used by the Level 1 processing. This processing software makes use of subroutines supplied by POEMS collaborators most familiar with specific detectors. In particular, Chicago (UC) will supply routines to convert the Cherenkov, scintillator and calorimeter detector "channels" to "physics" units (i.e. photon number, Lorentz factor, energy deposit, particle charge), Goddard Space Flight Center (GSFC) will provide a subroutine to determine X,Y positions and trajectories from the hodoscope data, and Kiel will supply routines for converting the EES data. In addition to these conversions, the Level 1 processing will also determine the event quality, calculate the pointing vector in terms of right ascension and declination, determine the directional geomagnetic cutoff for each event and output the data records in the standard format. The resulting Level 2 datasets include all EES and MS events and gamma ray data transmitted by the spacecraft.

The highest processing level anticipated is shown in Figure 26. During Level 2 processing MS Events are selected and, using routines supplied by collaborators, the particle track through the magnetic field is fit, the particle rigidity is determined, events which produce a shower in the calorimeter are identified and the particle mass and energy are determined. Further the event is classified and labeled with a preliminary identification (i.e. positron, electron, proton, etc.) and a flag indicating the reliability of this identification is added. Finally, flags indicating whether the event occurred during solar and/or geomagnetic quiet time, as determine from ancillary data in the POEMS Science database, are added and the Level 3 MS Event data volume is written in a standard format. The Level 3 data is then analyzed by the collaboration to produce data products such as GCR electron and positron flux spectrum, GCR positron / electron ratios, geomagnetospheric radiation spectra and characteristics of SEP events. Such products, in conjunction with the Science Database, are used during the astrophysical interpretation.

3. Data Distribution

As the flight data is processed, the Level 1, 2 and 3 data will be made available online for collaborators to download over the network. In addition, as illustrated in Figure 27 we will also distribute these data to every collaborator on CD/R disk. CD/R, or CD-Recordable, uses the same formats and form factor as a CD-ROM disk, but is a write once media. Thus, a CD/R can be loaded and read on inexpensive CD-ROM drives which are widely available for

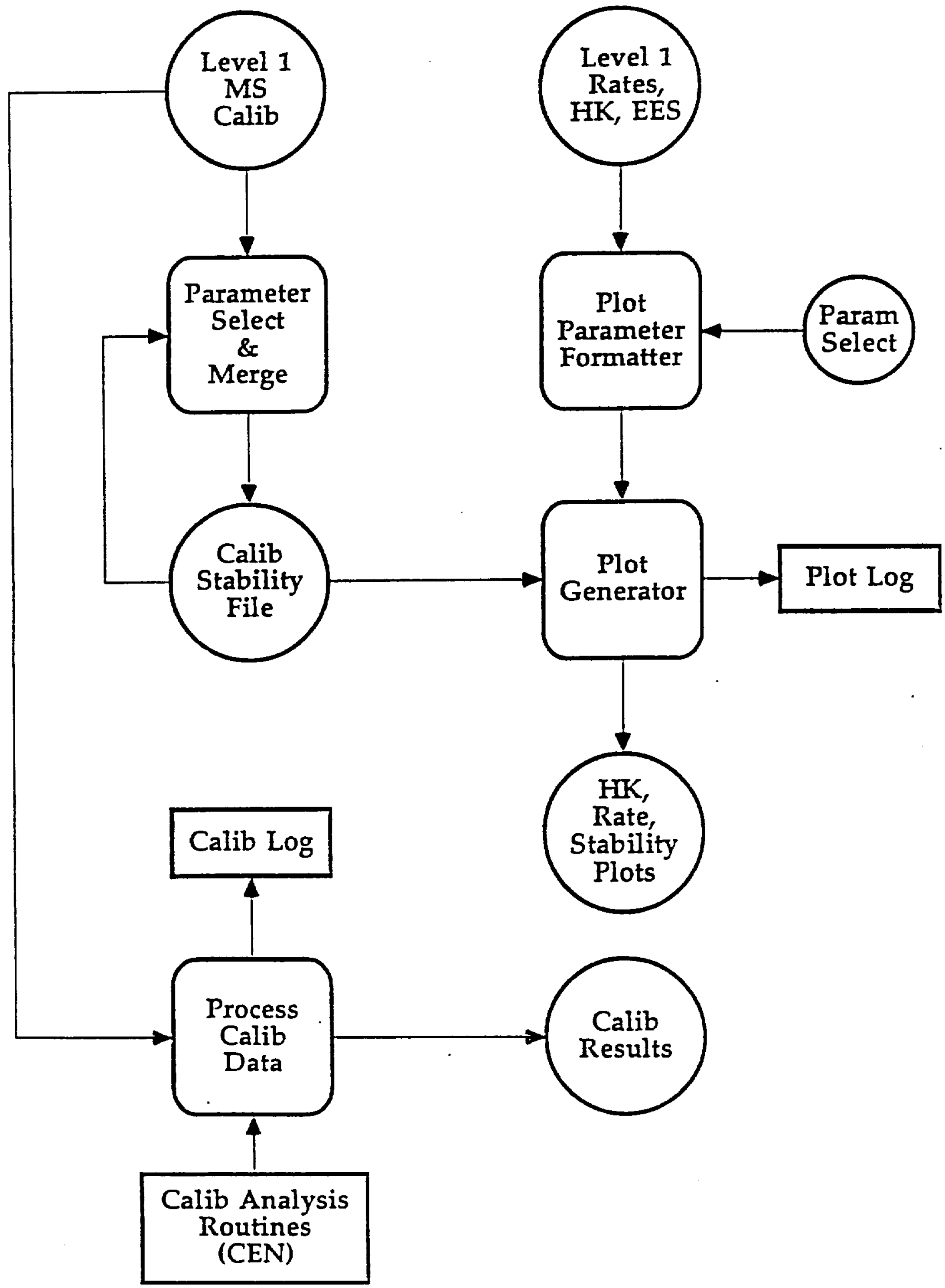


Figure 24. Proposed time-history plot generation.

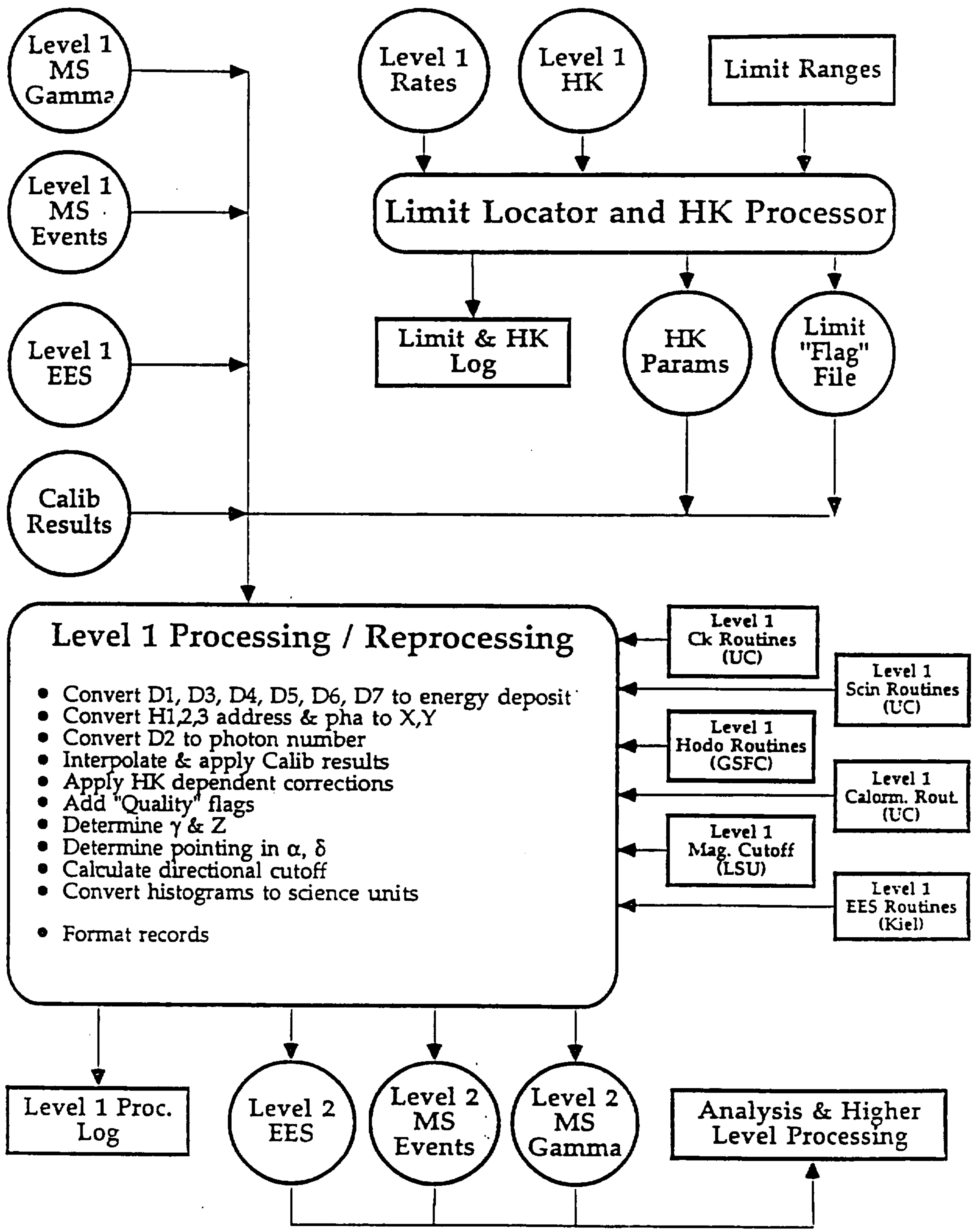


Figure 25. The Level-1 processing scheme.

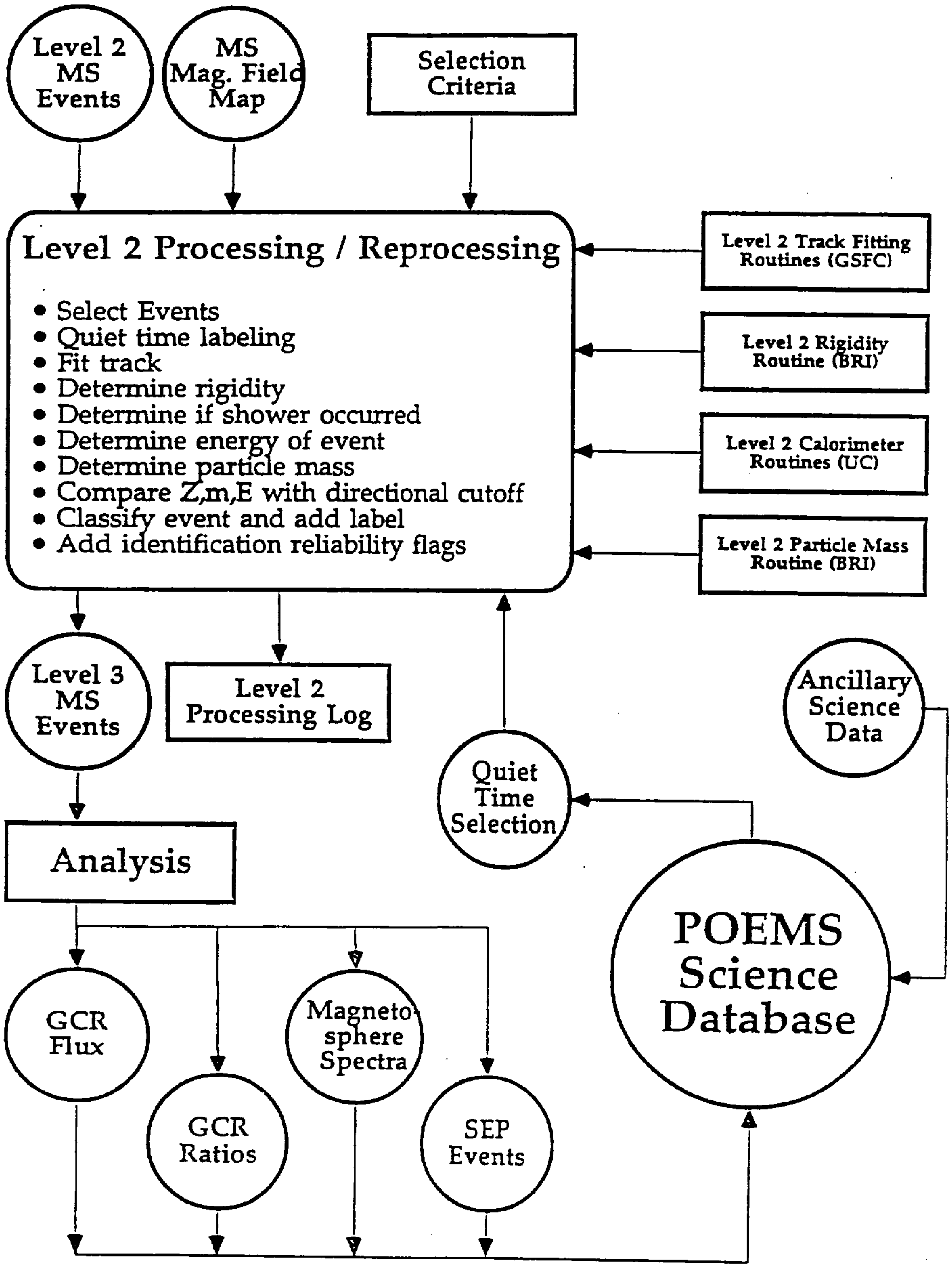


Figure 26. Schematic diagram of the Level-2 processing.

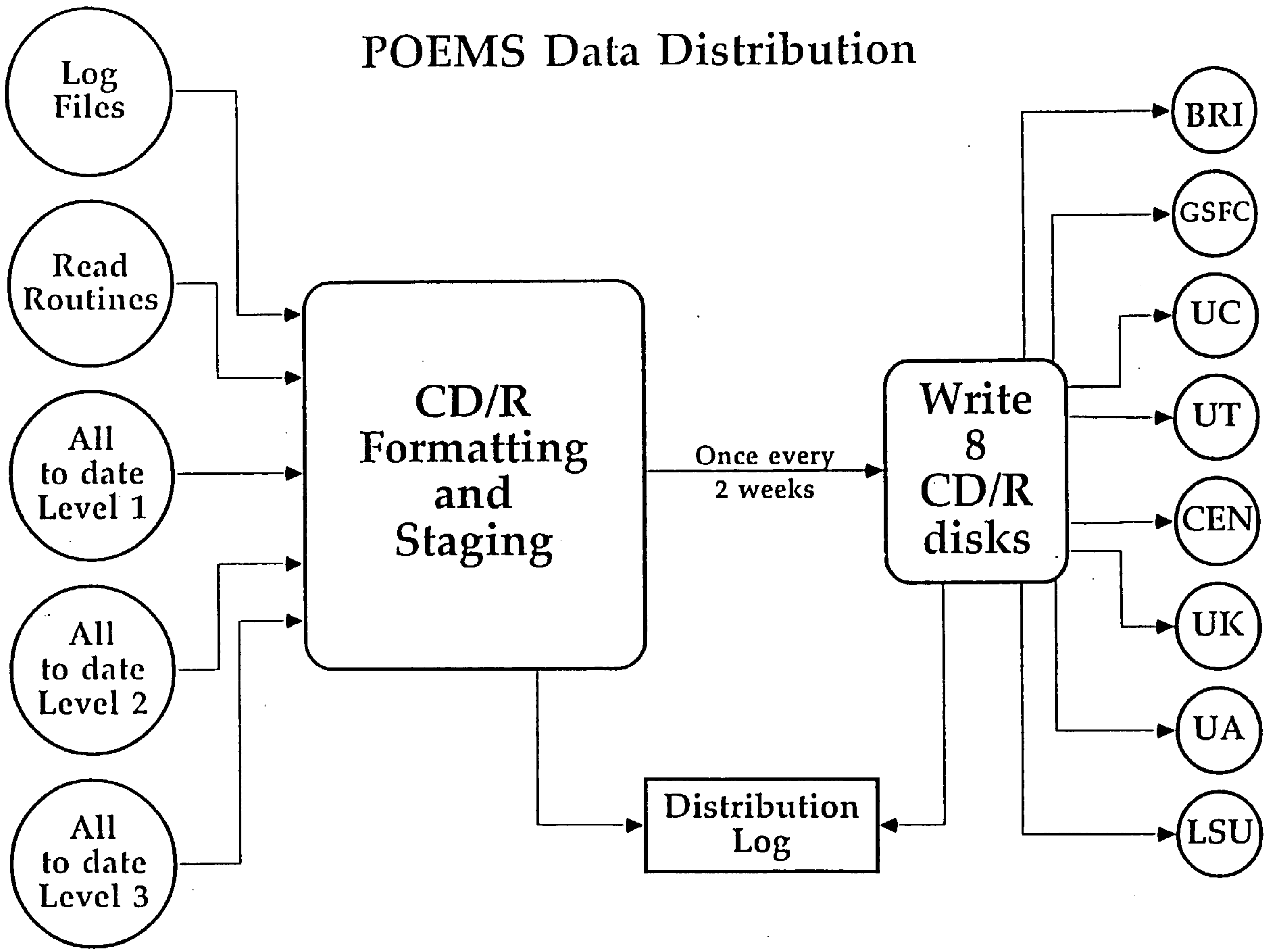


Figure 27. POEMS data acquisition.

essentially all platforms. In addition, CD/R media is expected to have a lifetime exceeding 30 years. Finally, each CD/R disk can hold up to 660 MB of data, so with the planned POEMS downlink data rate only two CD/R disks would be needed for each year of data. For these reasons CD/R is well suited for distributing and archiving the POEMS data.

Following the daily processing, all Level 1, 2 and 3 data as well as associated data access routines, processing log files and auxiliary information is loaded onto the CD/R staging disk. Once every 2 weeks the data on the staging disk is used to write 8 identical CD/R disks, one for each of the POEMS collaborating institutions, and shipped. The LSU copy will serve not only for the local science analysis but also as a backup data archive. This process will continue until the staging disk is full, approximately every 2 to 3 months, when a final set of CD/R disks are written and the staging disk is erased, preparing it for the next series of processed data. Thus, the final disk in a series will contain all Level 1, 2 and 3 processed data cumulative since the last staging disk reset.

4. Hardware Requirements

As the POEMS daily download is not expected to be very large, the hardware requirements for the ground data processing system are modest. All processing will occur on a central system capable of 40 to 50 Mflops and containing about 96 MBytes of real memory. Such a system can be obtained at today's prices for less than $30,000. To hold the operating system, development tools, processing system, raw data, intermediate processing file, log files, calibration parameters, and processed results, the ground system will also require three large disks (1 GB to 2 GB each). Two 4mm DAT tape drive will be used for daily system and data backup and a laser printer will be needed for printing log files and plots. A CD/R recorder system including controller, staging disks, CD/R drive and software will be required for generating the data distribution. The online POEMS Science database will be supported by two CD-ROM 7 drive servers along with available hard drive space on the central system.

5. Implementation Timeline

The timeline for the design and development of the POEMS ground data processing system is shown in Figure 28. During the design phase the ground data system software and data flow will be fully defined including: 1) establishing the code, documentation and data standards, 2) identifying all modules and their associated function, 3) defining the interface between these modules, 4) determining the format and content of all processing log files, 5) determining the form and content of the environment and diagnostic plots, 6) designing specifications for the processing routines to be supplied by the Co-Investigators, 7) establishing the record structure and format of the Level 1, 2 and 3 data, 8) interacting with the Flight Operations Team (FOT) to establish algorithms for calculating UT, spacecraft position and pointing from the attitude / orbit data, 9) identifying the housekeeping parameters and rate limits for Level 1 processing, 10) determining the event selection criteria, and 11) defining the Level 1 and Level 2 processing algorithms. A preliminary design will be available by the PDR and a final design will be ready for the CDR.

The processing hardware will be ordered and installed during the first quarter of the Development phase and implementation of the designed processing software will begin. Each major software category (Ingest and Integrity, Data Formatter, Plotting, Distribution, etc.) will be developed in sequence and tested as it is completed. To proceed with developing the high level processing software, Co-Investigator subroutines for calibration data processing will need to be received by the fourth quarter of the development phase, the routines for Level 1 processing by the fifth quarter and those for Level 2 processing by the first quarter of integration phase. All software through Level 1 processing (i.e. generating a Level 2 data volume) will be completed and tested by the MOR. This will enable data generated during the

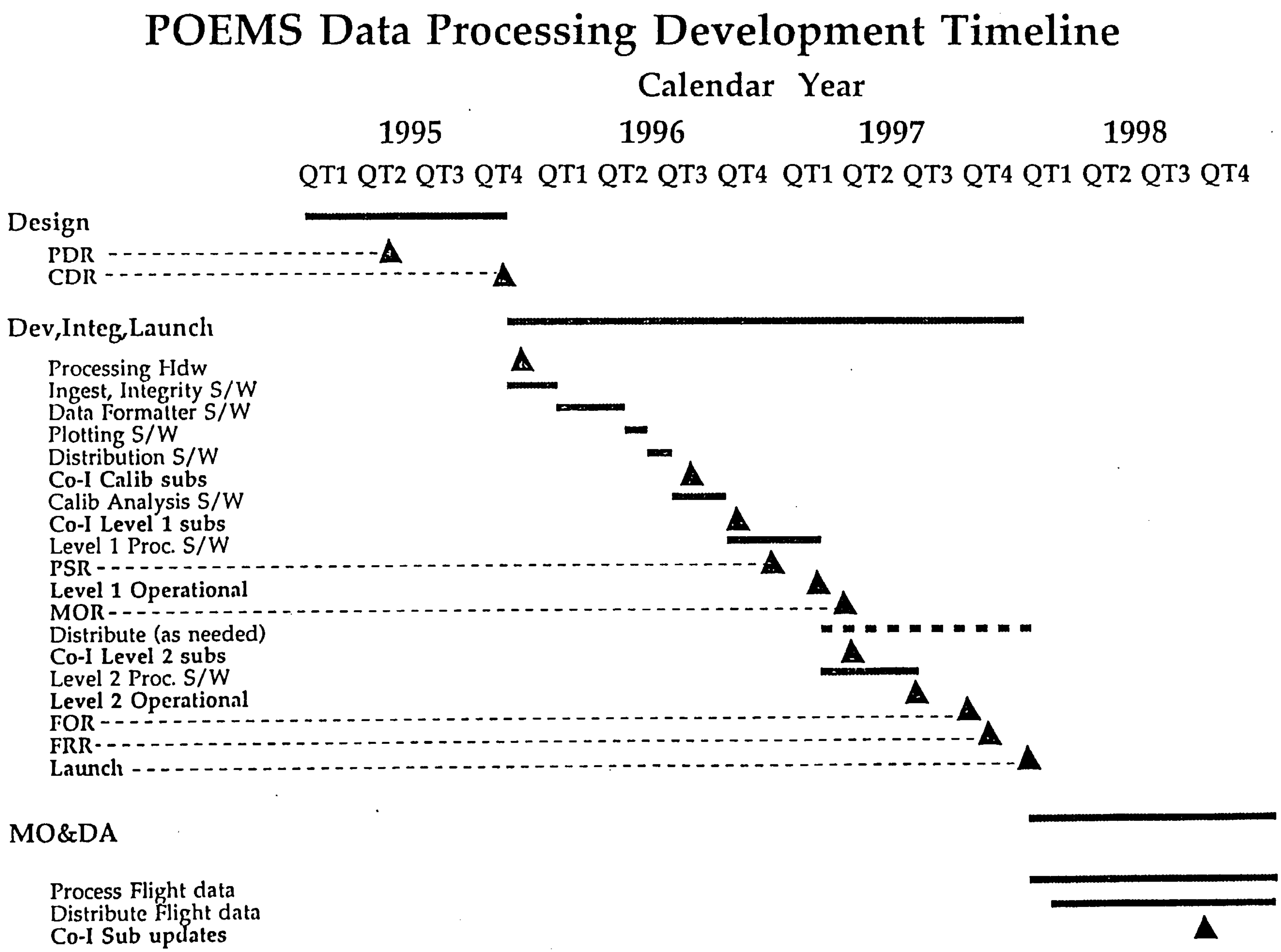


Figure 28. Time-line for implementation of the POEMS data processing system.

Integration and Test phase to be processed through the data system (providing an end-to-end test) and distributed, as needed, for analysis. The final software components of the ground data system -- Level 2 processing -- are expected to be operational approximately 6 months prior to launch.

The full system will begin processing flight data shortly after launch. As these data are analyzed, modifications and/or updates to the processing algorithms, parameter files, or subroutine may be required. Thus, periodically during MO&DA the processing software will be updated and all prior data will be reprocessed and distributed anew.

Appendix B

Final Report from the
Laboratory for Astrophysics and Space Research
of the
University of Chicago

SMEX/POEMS
Phase I Final Report
(Submitted to Bartol Research Institute 12/20/94)

The University of Chicago under contract with the Bartol Research Institute has completed the following tasks:

- Design of the Spectrometer was completed and submitted. Engineering drawings were completed as required. These are summarized in the Mission Implementation (MIP) attached here.
- The GSE required for payload integration was developed in discussions with GSFC/SMEX and the other members of the POEMS team.
- A Magnet Spectrometer (MS) testing scheme was developed and the test levels are summarized in the MIP.
- The MS design was subject to major updates approximately four times during Phase I. A detailed description of the final MS component masses was provided By UC.
- Input was provided to the Mission Requirements Document and LSU/Data Processing Plan and associated Science Operations Center (SOC).
- The University of Chicago Subassembly Assurance Plan (SAIP) describes the approach developed and agreed on for performance assurance for this project.
- The Implementation Plan and the Phase III schedules have been addressed and the details are given in the MIP.
- The UC supported the POEMS meetings held throughout Phase I to develop the payload and interfaces to the SMEX/GSFC Project Office.
- Implementation and Mission Costs were provided to BRI based on the work breakdown structure defined in the UC MIP.

The UC Mission Implementation Plan is attached.

MIP Table of Contents

1. Description 2
2. UC Task Overviews 3
3. Work Breakdown Structures 5
4. Implementation Plan 5
5. Quality Assurance 7
6. Testing and Analysis 7
7. Resources 8

1 Description

This plan describes the proposed participation of the University of Chicago (UC) in the small explorer mission (SMEX) - Positron Electron Magnet Spectrometer (POEMS). UC is primarily responsible for producing a major part of the Magnet Spectrometer instrument MS and for integration and testing of the overall POEMS payload incorporating the Energy Extension System (EES) which will be provided by other project collaborators.

The MS instrument consists of three subassemblies and an associated electronics box. The layout of these subassemblies on the spacecraft mounting plate are shown in Figure 1. These are (A) gas cherenkov counter, (B) magnet/hodoscope assembly, and (C) calorimeter/gamma ray detector. The University of Chicago is responsible for the design, fabrication, and testing of these components except for the silicon strip hodoscopes and associated electronics which are to be supplied by the GSFC LHEA group and the magnet assemblies to be provided by the University of Turku (UT) in Finland. The magnet spectrometer electronics box will be supplied by the University of Kiel (UK), Germany group.

UC will purchase, test and package photomultiplier tubes (PMTs) associated with the MS instrument. PMTs for the magnet bore anticoincidence shield will be sent to collaborators at UT for incorporation into the magnet assemblies of (B).

The overall POEMS instruments mounted on the spacecraft interface plate is shown in Figure 2. There are four subassemblies associated with the MS and two subassemblies for the EES. UC will take delivery of these items and the Spacecraft Interface Plate (SIP) at Chicago. The subassemblies will be integrated to the SIP and tested to electrical and environmental specifications. The electrical tests will be performed at UC and the environmental tests are planned to be performed in the Chicago area, at Minneapolis and in GSFC. UC will provide the lead support for these tests.

2 UC Task Overviews

2.1 Deliverable Subassemblies

2.1.1 Cherenkov Counter (A)

This subassembly, see Figure 3, consists of a plastic scintillation counter combined with a sealed vessel containing 30psia of ethylene gas. The cherenkov light emitted in this gas is reflected by a plane mirror onto a 5cm diameter PMT (Hammamatsu type R2757). The gas vessel will have a sufficiently low leak rate to remain operable for several years without requiring top-off. The plastic scintillator is a disc viewed by 2x1.5cm pmts (Hammamatsu type R4162), this provides one of the two master trigger signals for the MS spectrometer events. The operation of this assembly can be verified using naturally occurring ground level cosmic ray particles.

2.1.2 Hodoscope/Magnet (B)

The center section of the MS, see Figure 4, consists of a permanent magnet assembly and a silicon strip hodoscope assembly for measuring the paths of charged particles in the magnetic field. The magnet consists of two sections each of which is constructed from eight blocks of high field magnet alloy. The blocks are held in place by structural plates which also provide guide slots for the hodoscope assembly. The hodoscope consists of three planes of silicon strip detectors, two outside the magnet and one in the center between the two magnet sections. The alignment between the hodoscope planes is accomplished by the strutural plate assembly. The operation of this assembly can be verified with cosmic rays. The hodoscope electronics is mounted in a piggy back box since the conections between the detectors and the readout circuitry must be kept as short as possible. This electronics box is also mounted to the structural plates. Each magnet section has an associated anti-coincidence plastic scintillation counter which is viewed by 2x1.5cm diameter pmts

2.1.3 Calorimeter/Gamma Ray detector (C)

The third section of the MS, shown in Figure 5, consists of nine CsI(Tl) crystals which act as an electromagnetic calorimeter for particles passing through the magnet bore and also as a solar gamma ray detector for photons coming in through the side wall of the assembly. The crystals are viewed by nine 2x1cm photodiodes (Hammamatsu type S2744), the threshold energy for a single crystal detector is expected to be 1MeV. The crystal assembly is completely surrounded by scintillation counters. One of these is the second trigger counter, a small disc above the crystal stack - this is viewed by one 1.5cm pmt. A second scintillator on the other side of the crystal stack is a penetration counter again viewed by one 1.5cm pmt. Surrounding the sides of the crystal stack is a third scintillator viewed by 2x1.5cm pmts. This is used as an anticoicidence counter to veto events where charged particles penetrate the CsI counters from the sides.

2.2 Integration

2.2.1 MS Integration

The MS subassemblies (with the exception of the complete hodoscope version of (B)) will be pre-integrated for a fit/alignment check of the MS mechanical components on a simulated spacecraft interface plate provided by UC.

2.2.2 POEMS Integration
UC will take delivery of the 6 subassemblies of the POEMS instrument payload and integrate them to the SIP, provided by GSFC SMEX project office. UC will perform functional/electrical tests on the assembled payload

2.3 Testing

2.3.1 MS subassembly testing
UC will perform subassembly testing on MS components (A) and (C). The tests and levels are shown in Table 1. PMTs delivered to UT will be Qual./Flight tested to the levels in this table.

2.3.2 POEMS payload level testing
The integrated POEMS payload will be subjected to the tests/levels shown in Table 1.

2.4 Modelling

2.4.1 MS Thermal model
UC will provide a SINDA thermal model of the MS instrument subassemblies A,B, and C. The number of nodes and complexity of this model will be determined in consultations with the project office.

2.4.2 MS Mechanical model
A mechanical model of the subassemblies associated with the MS will be provided by UC. The level of detail and format of this model is TBD.

3 Work Breakdown Structures

The WBS for the UC tasks are represented by block diagrams as follows:

3.1 MS Subassembly A WBS *Shown in Figure 6*

3.2 MS Subassembly B WBS *Shown in Figure 7*

3.3 MS Subassembly C WBS *Shown in Figure 8*

3.4 MS PMT assemblies WBS *Shown in Figure 9*

3.5 POEMS integration and Testing *Shown in Figure 10*

4 Implementation Plan

4.1 Hardware and Integration/Test schedule

The UC implementation plan and schedule for these activities is shown in Table 2. (In the following all item numbers are referenced to this table) Procurement and packaging of the PMTs for the MS are addressed in items 1 and 2 of this table. The UC is the only collaborator working on hardware for subassemblies A and C of the MS. The work on these assemblies is shown in items 3 and 6. The processes associated with subassembly B are also shown for scheduling comparisons in items 4 and 5. The bulk of the magnet work (excepting the PMTs) shown in 4 will be performed by UT. The design work on subassembly B structure will be a joint effort between UC and GSFC LHEA as shown in item 5. Two flight magnet assemblies will be delivered to UC by UT, one of which will go to GSFC LHEA for the hodoscope integration after completing fit/alignment checks. The other will stay at UC for MS integration fit/alignment checks.

The spacecraft bracket described in item 7 holds the spacecraft interface electrical connectors. Design and location TBD.

Items 8 through 10 are associated with the integration of the MS and the POEMS payload at UC. In this plan the SIP must arrive at UC by 9/1/96 for the schedule to proceed.

Item 11 provides the plan for the testing of the complete POEMS payload before delivery to the GSFC SMEX office. Two months have been allocated for these tasks.

4.2 Spares Plan

UC will provide spare assemblies in component form for each of MS A,B and C. All scintillators and crystals will also have one spare. For the 5cm PMTs 5 will be purchased (1 required for the MS) and 2 will be brought to flight specifications. For the 1.5cm PMTs, 25 will be purchased (10 required for the MS) and 15 will be selected for building to full flight specifications. The photodiodes will be selected for low noise from 30 purchased (9 required).

4.3 Long Lead Items

Several long lead items have been identified which will require a purchase order to be issued before the CDR. These are:

5cm PMTs -(6-9 months lead)

1.5cm PMTs -(6-9 months lead)

photodiodes - (6 months lead)

potting material - (6 months lead)

optical coupling pad material - (6 months lead)

magnetic shielding material - (90+ days lead)

5 Quality Assurance

The UC subassembly assurance implementation plan (SAIP) is provided as an Appendix I to this document.

6 Testing and Analysis

6.1 Hardware Qualification

Hardware provided by UC will be tested to the levels specified in Table 1 for subassemblies for qualification of design. The gas container for the cherenkov counter of subassembly A will be tested by prototype construction and qualification testing.

6.2 Analysis

6.2.1 Thermal Analysis

The thermal modelling of the MS instrument will be based on a thermal control concept developed during phase I of POEMS. This divides the subassemblies A,B and C into 3 separate thermal areas by covering the assemblies with multilayer insulation blankets (MLI) on all sides except the attachment to the spacecraft. Subassemblies A and C are thermally connected to the spacecraft plate, subassembly B is isolated. The ~5W of power dissipated by B are radiated by a plate connected to the hodoscope electronics box. This concept works well in the modelling performed in phase I. The report for the model developed in the study phase is attached as Appendix 2. A vendor has been identified (Ball Areospace) to perform this study during phase III of POEMS.

6.2.2 Mechanical Analysis

The mechanical modelling of the MS will be performed seperately on each of subassembly A,B and C. The details of this effort are TBD.

6.3 POEMS payload environmental testing

These tests as specified in Table 1 will either be performed at UC or at vendors in either Chicago (Vibration) or Minneapolis (Thermal Vac.). These vendors have been contacted and the feasibility and cost of performing these types of tests have been discussed. Acoustic testing, if required on the POEMS payload, will be performed at GSFC.

7 Resources

7.1 Key Personnel

Key Personnel for this program at UC and their roles are as follows:

Simon Swordy - Co-I and Scientist responsible for the development and testing of the detectors developed at UC. Also overall program management. Experience includes detector design and testing for CRNE experiment flown on Spacelab-2 in 1985, several electronic detector systems for high altitude balloon payloads

Bruce McKibben - Co-I and Scientist providing science rationale for the mission and detector development effort. Experience includes the COSPIN instrument on the Ulysses spacecraft and several other small spacecraft electronic detectors for charged particles in the solar system.

Wayne (Skip) Johnson - Lead Mechanical Engineer providing the MS assemblies and integration of the POEMS payload. Also responsible for POEMS configuration management. Experience includes mechanical design of Spacelab-2 payload and participation in the design effort for several space instruments and high altitude balloon experiments.

Fred Sopron - Project Assurance Manager for the POEMS effort at UC, responsible for QA and overall assurance issues. Experience includes space instrument electrical engineering for many payloads and environmental testing schemes.

7.2 Facilities and Equipment

The UC has designed and executed experiments for 33 highly succesful space missions, including the first probes to the Moon and to Mercury, Mars, Jupiter and Saturn- as well as over 100 experiments on high altitude balloon flights. The general scientific theme of most of this work has been the study of energetic charged particles, plasmas and radiations in a wide range of astrophysical settings. The success of the UC group is largely possible through a NASA grant in the early 1960's leading to the establishment of the Laboratory for Astrophysics and Space Research, (LASR), within the University's Enrico Fermi Institute. LASR was created to join in a single laboratory the academic staff, students and technical experts involved in space science research. All faculty members hold joint teaching appointments within the departments of physics, astronomy or chemistry at UC.

The technical services group within LASR provides engineering, design, fabrication test and launch support for space flight instrumentation on a full time professional basis. Excellent central shop facilities at the University, and well maintained special purpose facilities within LASR make it possible to construct sophisticated space instrumentation 'in-house' at UC.

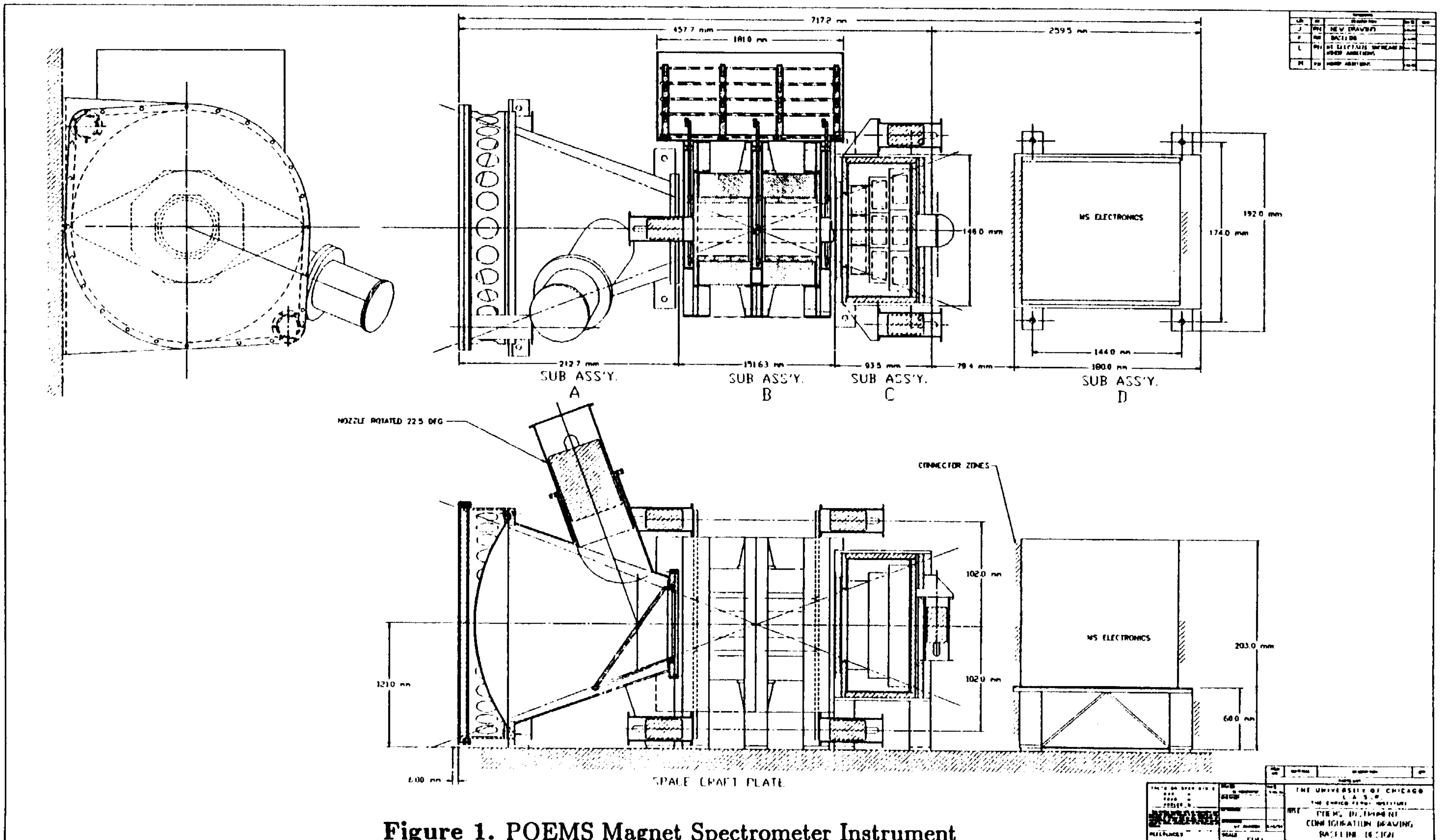


Figure 1. POEMS Magnet Spectrometer Instrument

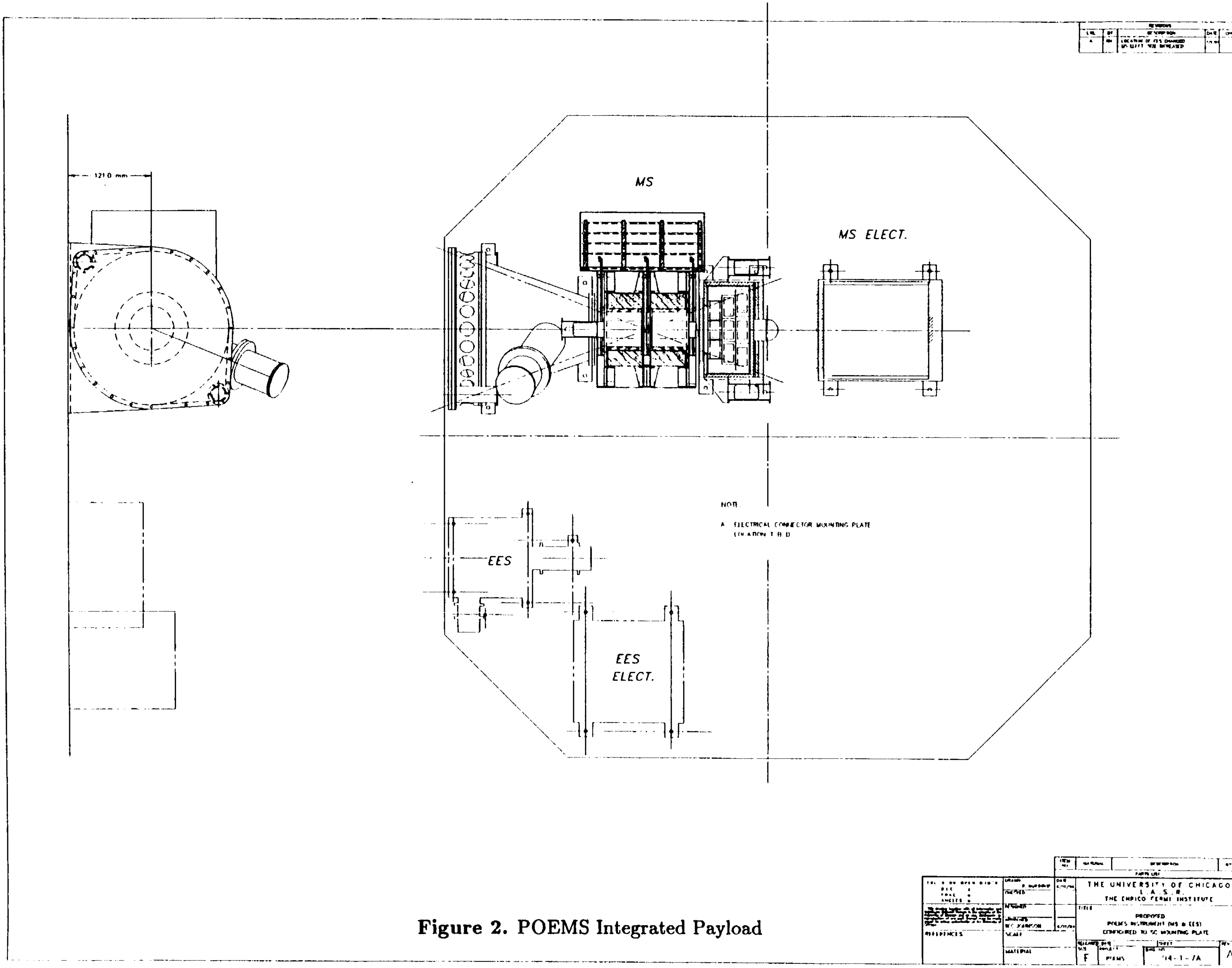
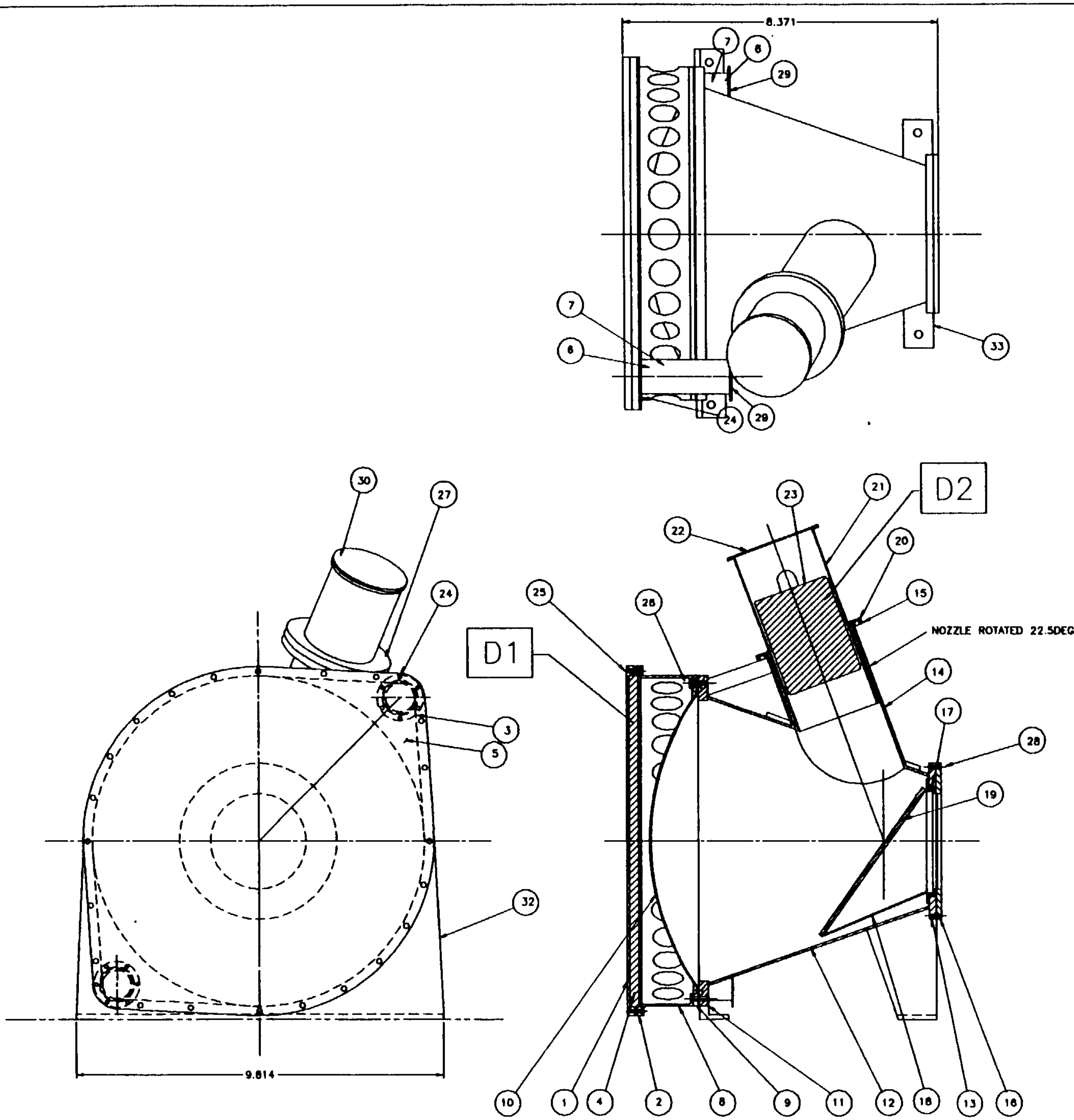


Figure 2. POEMS Integrated Payload



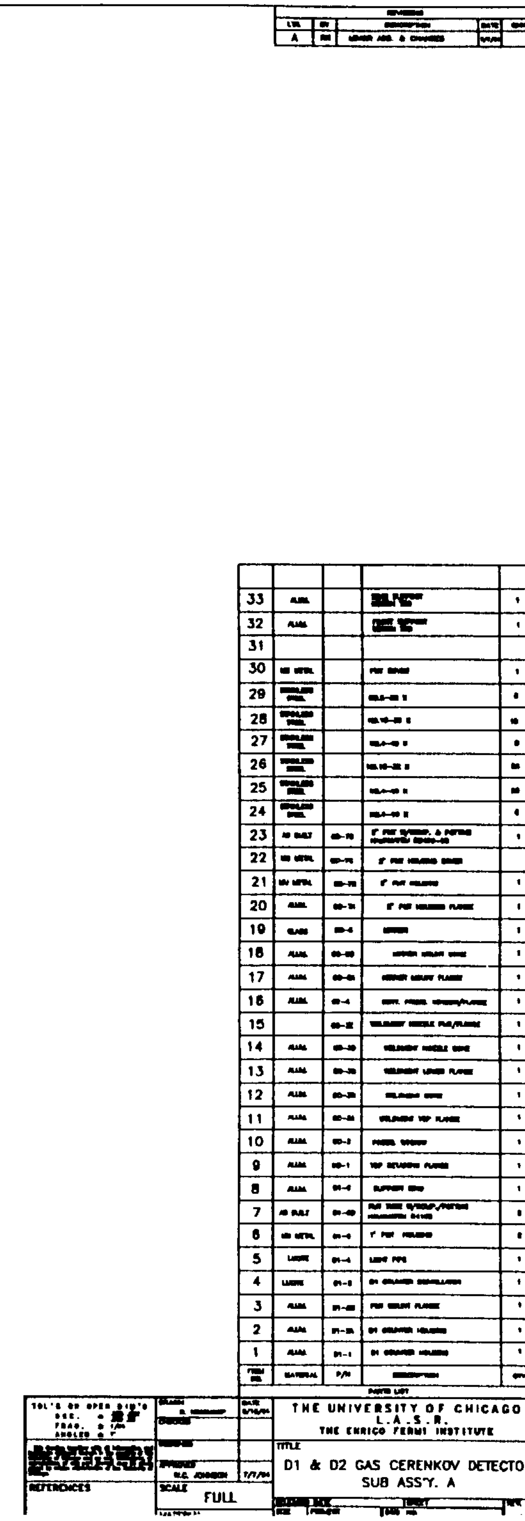


Figure 3. MS Subassembly A

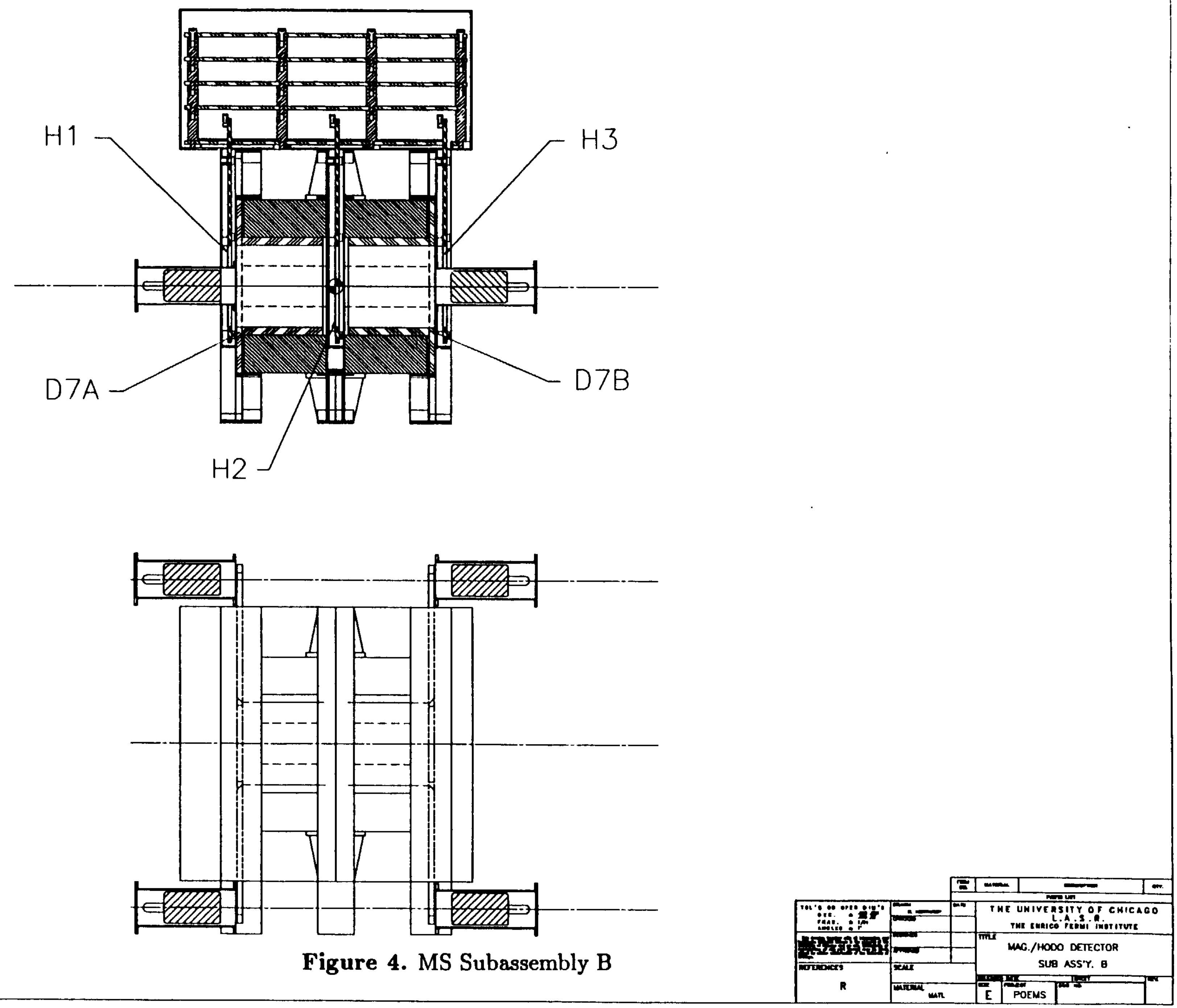


Figure 4. MS Subassembly B

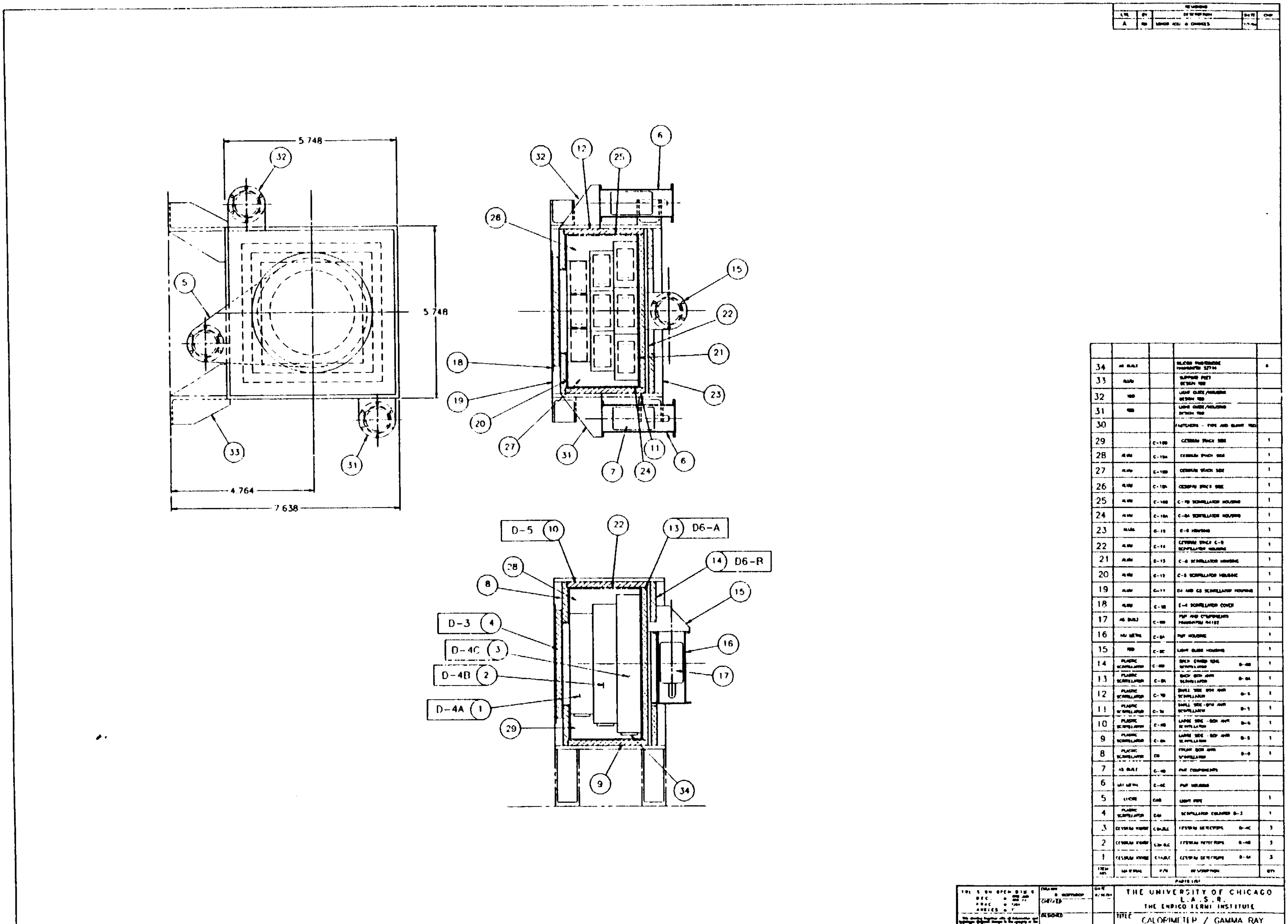


Figure 5. MS Subassembly C

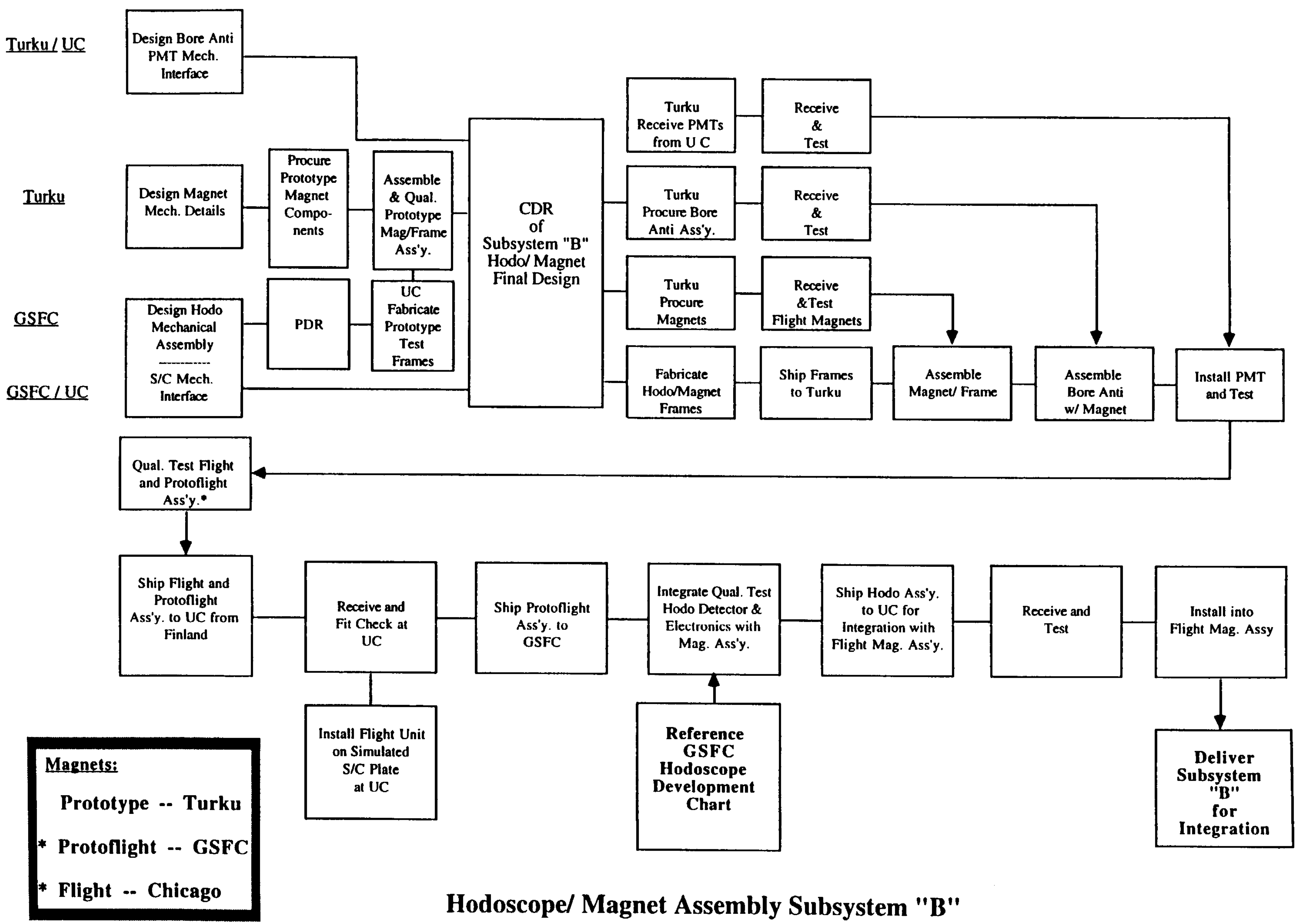
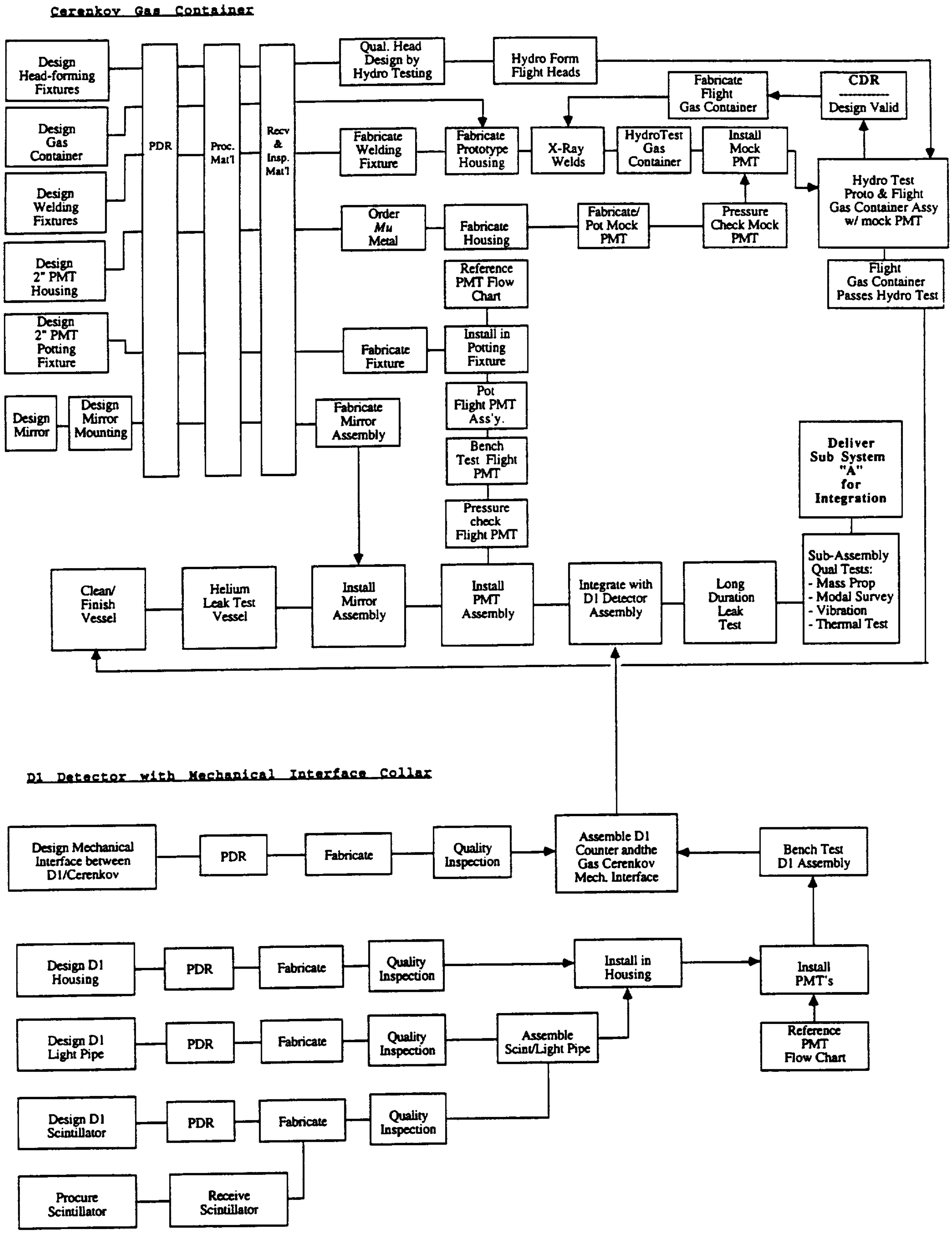


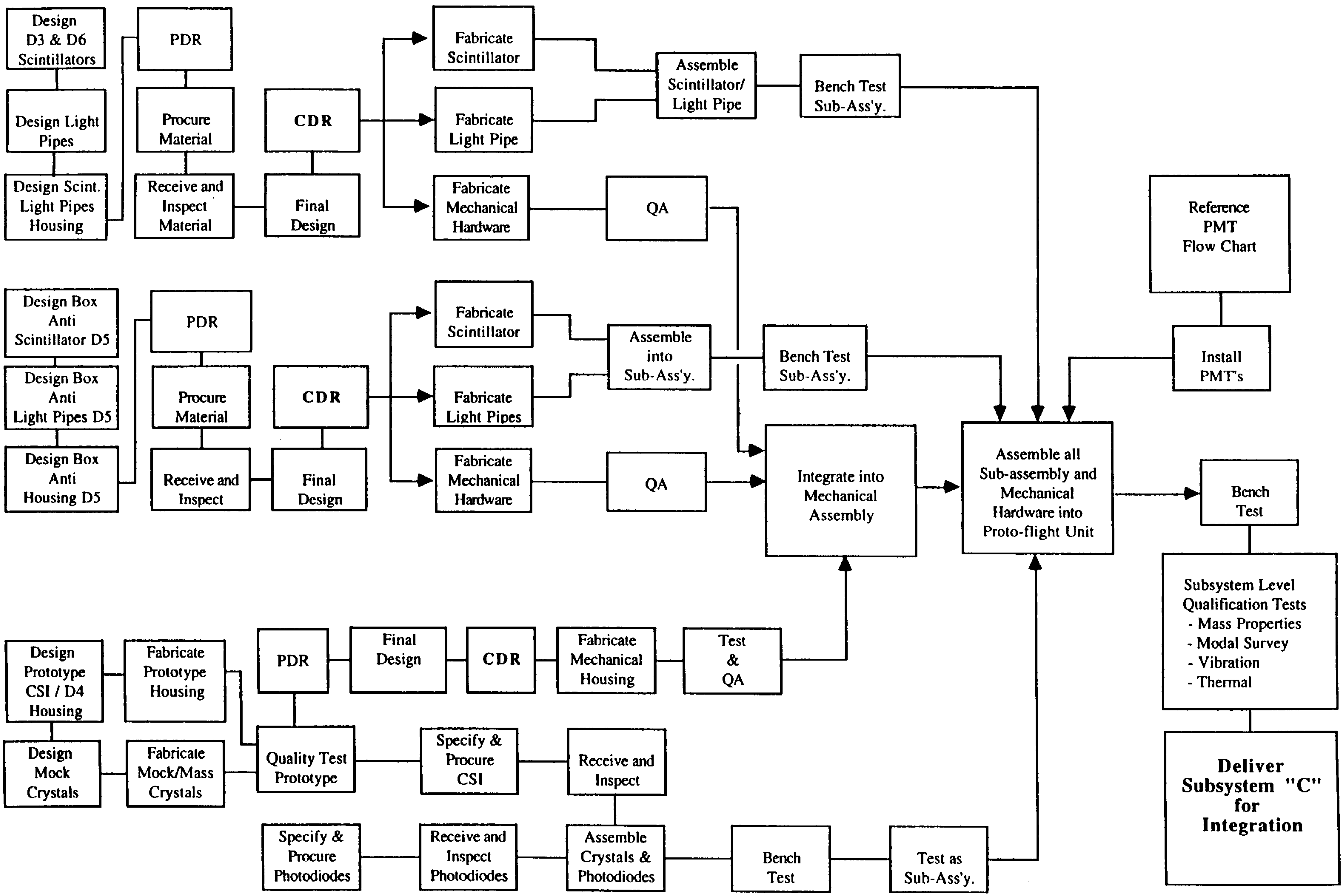
Figure 7. WBS for Subassembly B



SMEX/POEMS Subsystem "A"

7/26/94

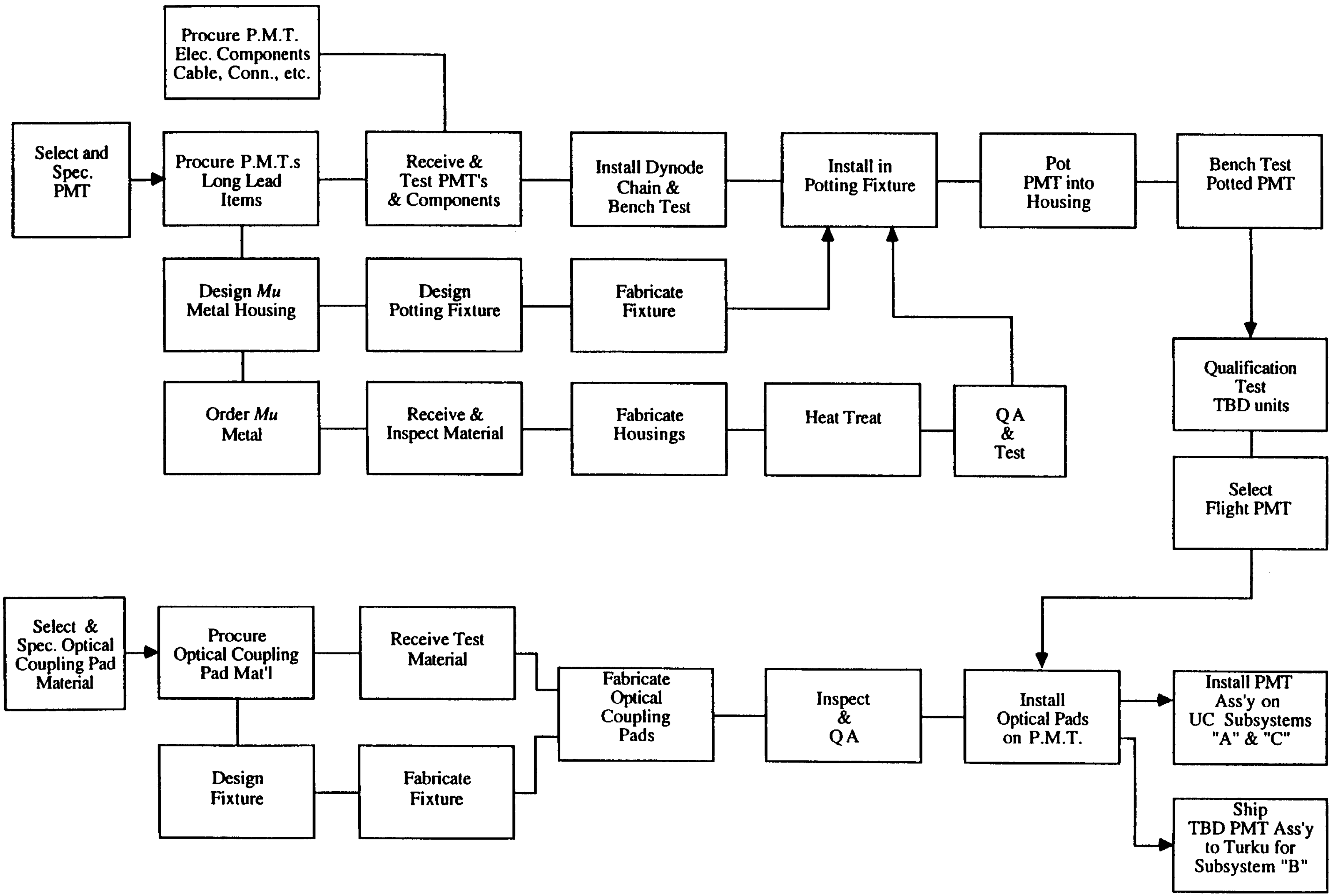
Figure 6. WBS for Subassembly A



Calorimeter/Gamma Ray Detector - Subsystem "C"

7/19/94

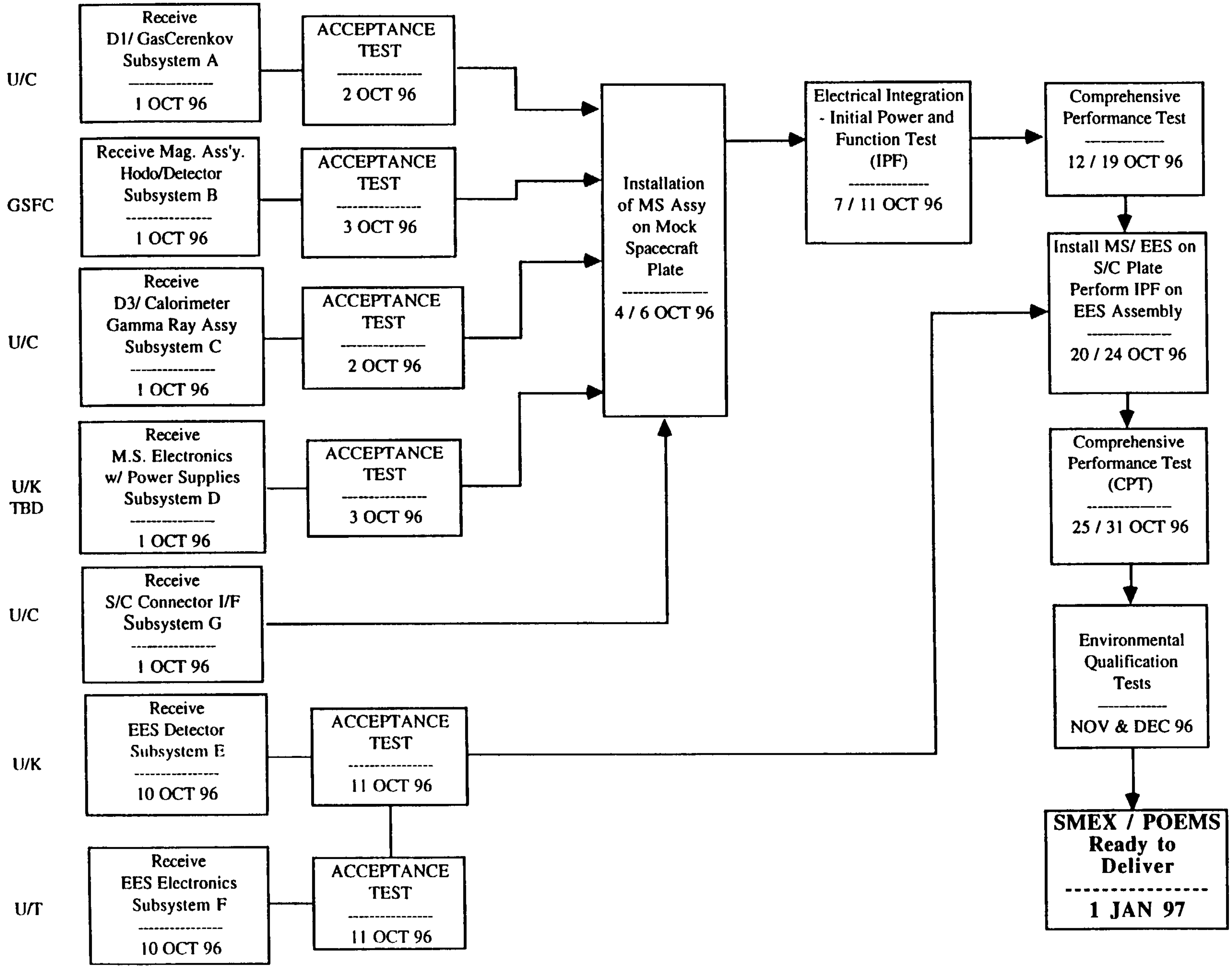
Figure 8. WBS for Subassembly C



**PMT / OPTICAL COUPLING PAD
DEVELOPMENT CHART**

7/18/94

Figure 9. WBS for PMT assemblies



Integration and Test of SMEX/POEMS Subsystems A, B ,C, D, E, F, G
Ref. SOW Phase III/IV Matrix 7.0

7/20/94

Figure 10. WBS for Integration and Test of POEMS

	Modal Survey	Random Vibration	Sine Sweep	Sine Burst	Mechanical Shock	Acoustic	Mass Properties	EMC	Magnetics
SWAS Instrument	NO (ETU structure)	Qual=14.1 grms SWAS (7.3.4.5)	YES	YES	NO S/C level	NO S/C	YES	YES	NO S/C
SMEX/POEMS Subsystem level	YES GEVS(2.4.1.2)	(Prototype) Qual=8G rms@ 4 mins (Protoflight) Qual= 8G rms@ 2min (Flight) Flight=5.6G rms@ 2min	TBD	Fractional Analysis	NO	TBD (2.4.2)	Weight Center of Gravity Moment of Inertia	CEO1/CE03 RE02 RE04 CS01/CS02 CS06 RS03	NO
Payload Level (On Launch-vehicle Adapter)	TBD	(Protoflight) Qual= 8G rms@ 2min (Flight) Flight=5.6G rms@ 2min	TBD	NO	YES (2.4.3.1) sine-burst? 1.4 x flight	YES (2.4.2.2)	Weight Center of Gravity Moment of Inertia	CEO1/CE03 RE02/RE04 CS01/CS02 CS06 RS03	TBD

	Thermal Balance	Thermal Vacuum	TV Cycling	Bakeout	Pressure Profile				
SWAS Instrument	YES	YES	4 cycles	s/c level	Analysis				
SMEX/POEMS Subsystem	NO	NO	NA	Thermal Blanket & Wire Harness	Analysis				
Payload	Analysis (No active TCE)	YES	4 cycles	NA	Analysis				

Table 1. POEMS Environmental tests

ID	Name	Duration
1	**1 3/4" PMT DEVELOPMENT**	**270d**
2	**1.1 3/4" Prototype development**	**199d**
3	1.1.1 Spec. & Proc. 3/4" PMT's	5d
4	1.1.2 Receive and test	25d
5	1.1.3 Procure electronic components	5d
6	1.1.4 Receive - Inspect and test	5d
7	1.1.5 Develop base prototype	15d
8	1.1.6 Assemble PMT and components	5d
9	1.1.7 Design 3/4 PMT housing	5d
10	1.1.8 Procure Mu metal	1d
11	1.1.9 Receive and inspect	1d
12	1.1.10 Fabricate prototype housing	5d
13	1.1.11 Heat treat housing	7d
14	1.1.12 Design potting fixture	2d
15	1.1.13 Fabricate potting fixture	4d
16	1.1.14 Pot protoype pmt	5d
17	1.1.15 Qualify pmt assmby	10d
18	**1.2 3/4" Flight unit development**	**203d**
19	1.2.1 Final design	3d
20	1.2.2 Assemble PMT's and components	25d
21	1.2.3 Pre pot test	25d
22	1.2.4 Fabricate housings	15d
23	1.2.5 Heat treat housing	10d
24	1.2.6 Apply surface treatment	5d
25	1.2.7 Assemble PMT and housing	12d
26	1.2.8 Pot PMT-housing assembly	15d
27	1.2.9 Qualify for flight	4d
28	1.2.10 Design Optical Coupling Pad	1d
29	1.2.11 Develop fixture	10d

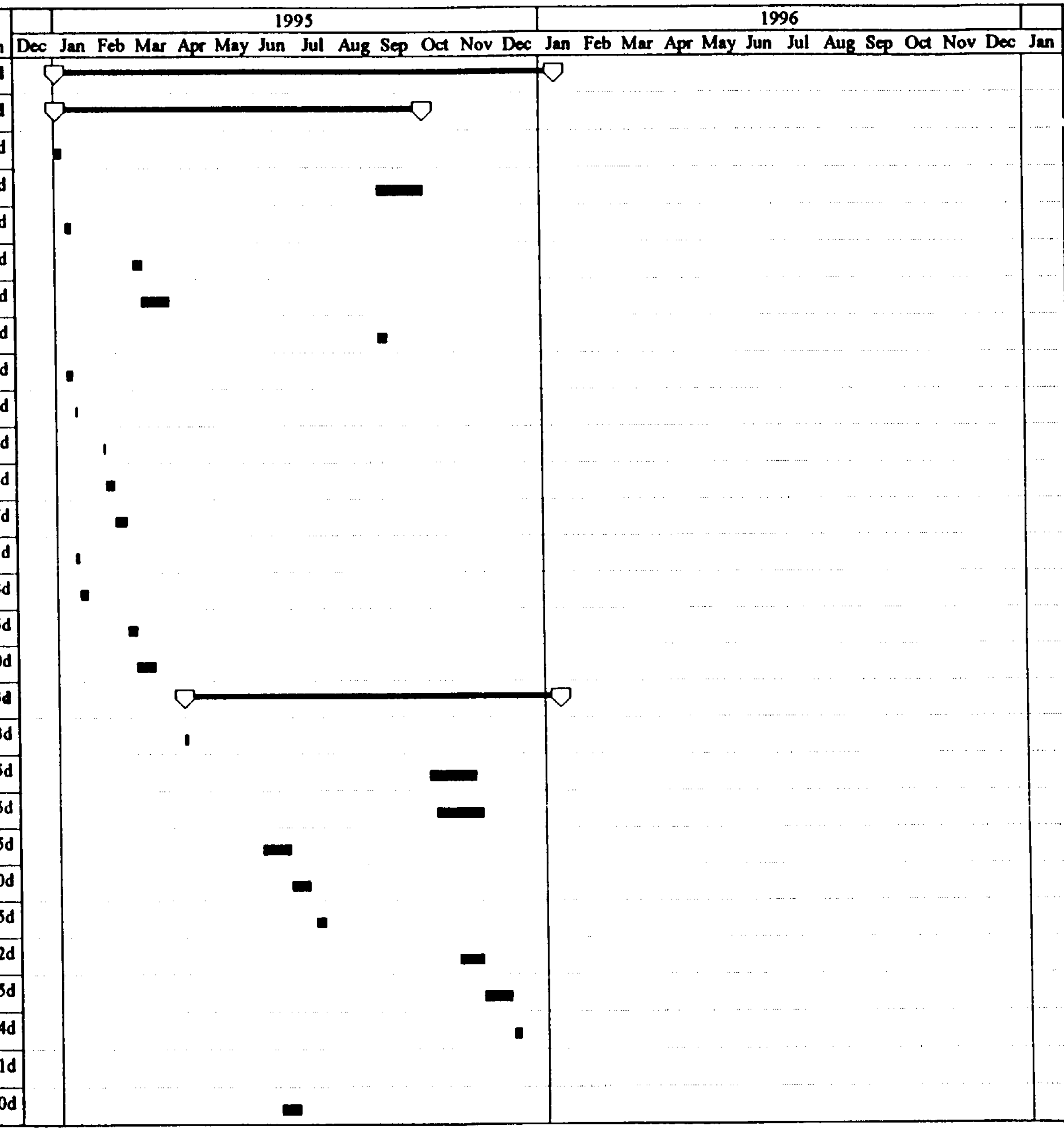


Table 2 UChicago MIP
Project: SMEX/POEMS
Date: 7/24/94

Critical — Progress — Summary
Noncritical — Milestone — Rolled Up

ID	Name	Duration
30	1.2.12 Fabricate Fixture	5d
31	1.2.13 Test Fixture	5d
32	1.2.14 Install optical coupling pad	4d
33	1.2.15 Deliver to sub-assembly	0d
34	1.3 PDR	0d
35	1.4 SCDR	0d
36		

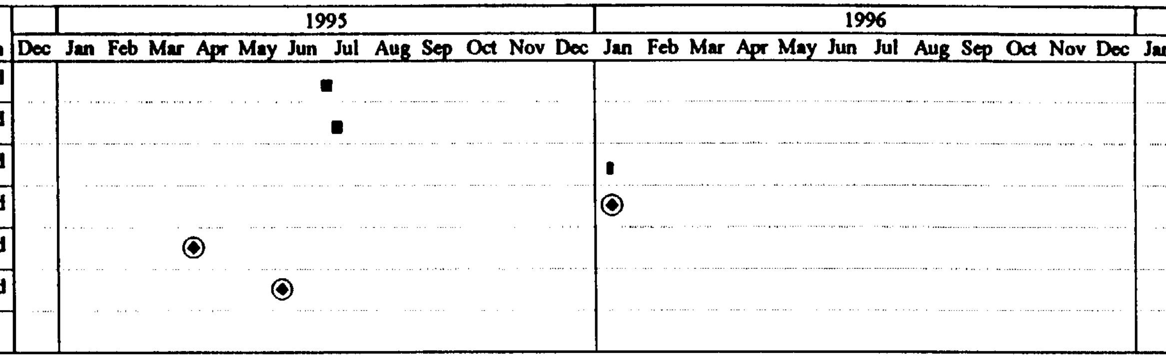


Table 2 UChicago MIP
Project: SMEX/POEMS
Date: 7/24/94

Critical
Noncritical
Progress
Milestone
Summary
Rolled Up

ID	Name	Duration
37	**2 [2"] PMT DEVELOPMENT**	**335d**
38	**2.1 2" Prototype development**	**189d**
39	2.1.1 Spec. & Proc. 2" PMT's	5d
40	2.1.2 Receive and test	10d
41	2.1.3 Procure electronic components	5d
42	2.1.4 Receive - Inspect and test	5d
43	2.1.5 Develop base prototype	15d
44	2.1.6 Assemble PMT and components	15d
45	2.1.7 Design 2" PMT housing	5d
46	2.1.8 Design potting fixture	2d
47	2.1.9 Fabricate potting fixture	5d
48	2.1.10 Fab. prototype housing	5d
49	2.1.11 Heat treat housing	7d
50	2.1.12 Pot protoype pmt	5d
51	2.1.13 Qual. by hyrdo test -PMT housing	5d
52	**2.2 [2"] PMT flight unit development**	**140d**
53	2.2.1 Pre pot test	25d
54	2.2.2 Final design	3d
55	2.2.3 Assemble PMT's and components	15d
56	2.2.4 Fabricate housings	15d
57	2.2.5 Heat treat housing	10d
58	2.2.6 Apply surface treatment	5d
59	2.2.7 Assemble PMT and housing	12d
60	2.2.8 Pot PMT-housing assembly	15d
61	2.2.9 Qual. for flight	25d
62	2.2.10 Deliver to sub-assembly	0d
63	2.3 PDR	0d
64	2.4 CDR	0d
65		

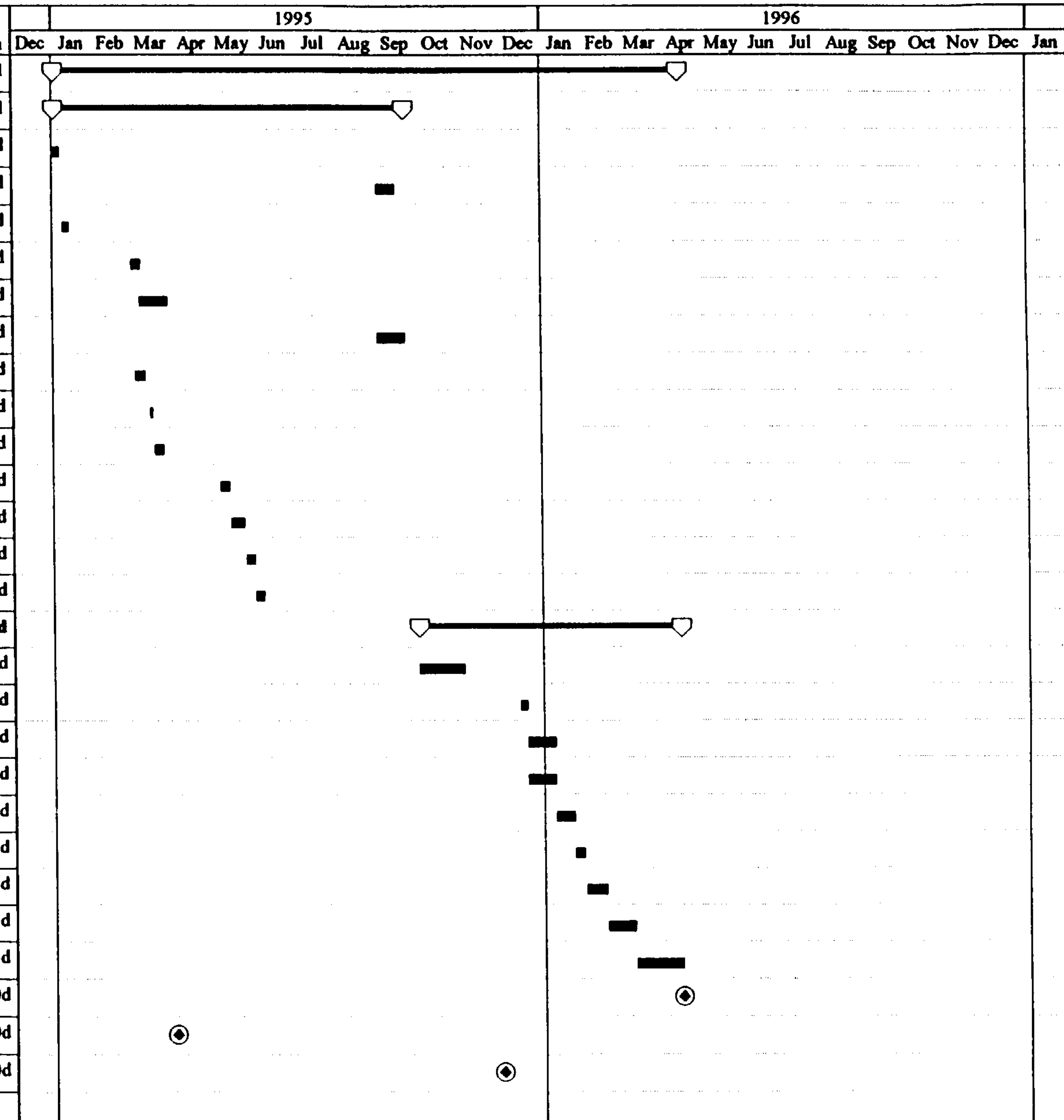


Table 2 UChicago MIP
Project: SMEX/POEMS
Date: 7/24/94

ID	Name	Duration
66	**3 DETECTOR SUBASSEMBLY " A"**	**403d**
67	**3.1 Prototype D2 gas container**	**165d**
68	3.1.1 Design vessel	30d
69	3.1.2 Design tooling for spinning	3d
70	3.1.3 Design head forming fixture	5d
71	3.1.4 Design welding fixture	5d
72	3.1.5 Design mirror mount	15d
73	3.1.6 Design mirror	5d
74	3.1.7 Procure spinning prototype	60d
75	3.1.8 Recive spinning & inspect	1d
76	3.1.9 X-ray spinning	5d
77	3.1.10 Procure materials	10d
78	3.1.11 Receive and test material	5d
79	3.1.12 Fab. welding fixture	10d
80	3.1.13 Fab. prototype housing	30d
81	3.1.14 X-ray housing weldment	5d
82	3.1.15 Fab. prototype housing head	5d
83	3.1.16 Qual. by hydro test - head design	10d
84	3.1.17 Qual. by hydro test - housing	10d
85	3.2 PDR D2 gas container	0d
86	3.3 CDR D2 gas container	0d
87	**3.4 Flight gas container**	**128d**
88	3.4.1 Flight Design	20d
89	3.4.2 Procure Material	2d
90	3.4.3 Receive & Test Material	5d
91	3.4.4 Fabricate welding fixture	10d
92	3.4.5 Fabricate P.V. vessel housing	30d
93	3.4.6 Fabricate P.V. heads	7d
94	3.4.7 Qual.&hydro. test	15d

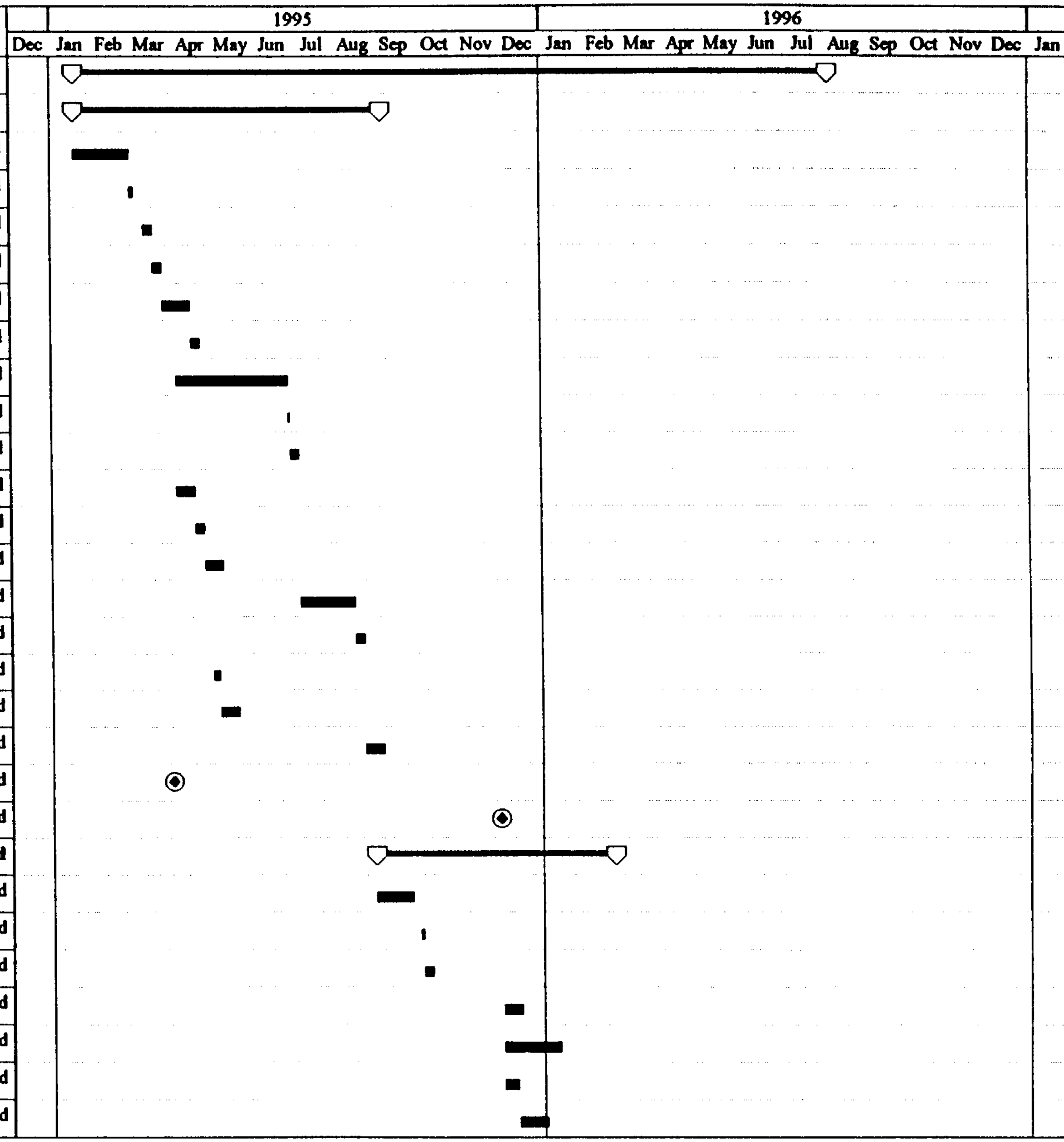


Table 2 UChicago MIP
Project: SMEX/POEMS
Date: 7/24/94

Critical — Progress — Summary
Noncritical — Milestone — Rolled Up

ID	Name	Duration
95	3.4.8 Apply surface finish	10d
96	3.4.9 Fabricate mirror mount	15d
97	3.4.10 Install mirror assembly	2d
98	**3.5 Flight Assembly " A"**	**330d**
99	**3.5.1 Fabricate D1 detector**	**75d**
100	3.5.1.1 Design D1 detector	20d
101	3.5.1.2 Procure Material	10d
102	3.5.1.3 Fabricate D1 housing	20d
103	3.5.1.4 Fabricate D1 scintillator	10d
104	3.5.1.5 Fabricate D1 light pipe	5d
105	3.5.1.6 Assembly D1 detector	10d
106	3.5.2 Fabricate mirror [3]	15d
107	3.5.3 Install PMT assembly on P.V.	1d
108	3.5.4 Bench test assmbly.	5d
109	3.5.5 Leak check Cerenkov assembly	45d
110	3.5.6 Assemble D1/Cerenkov container	5d
111	3.5.7 Subassembly "A" qual. test	30d
112	3.5.8 Deliver subassembly "A" to U/C	0d
113	3.6 PDR of assembly "A"	0d
114	3.7 CDR of assembly "A"	0d
115		

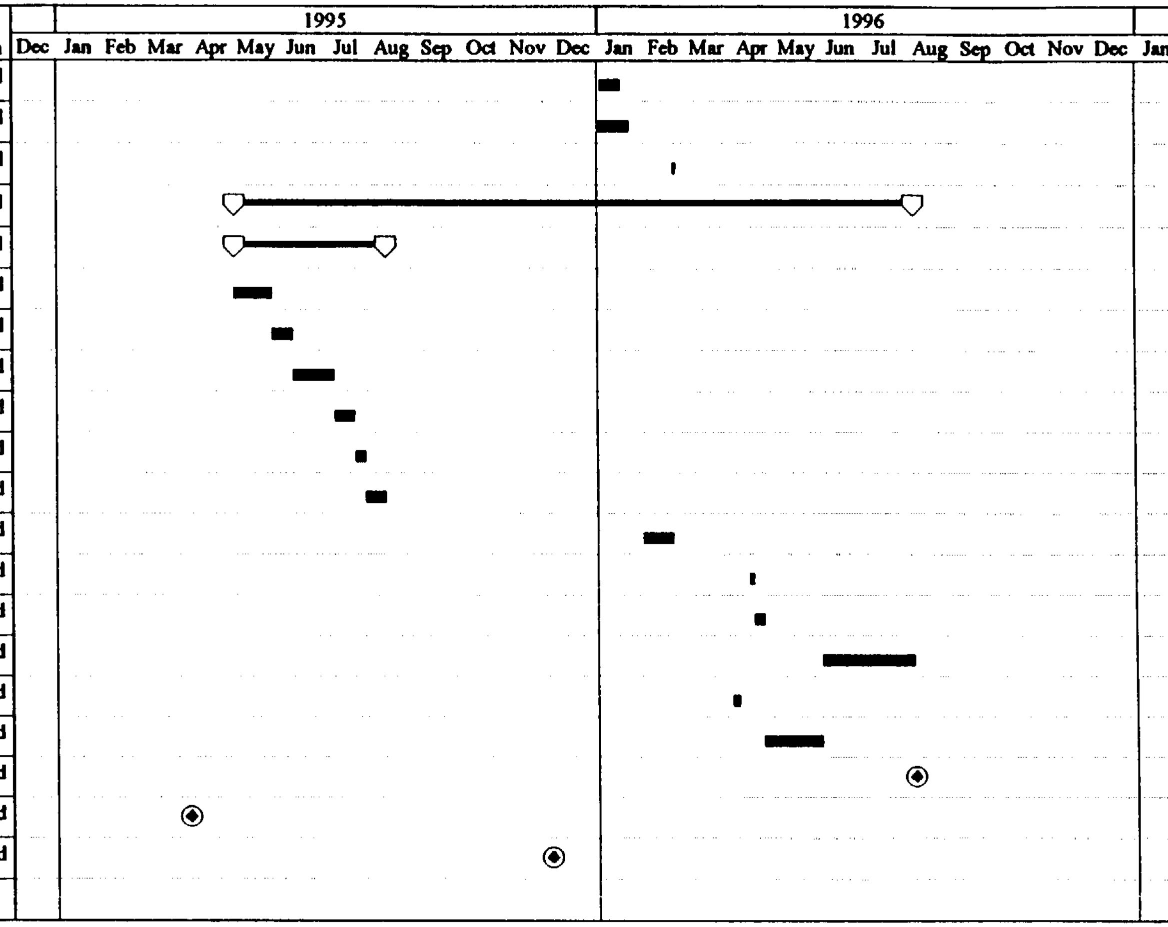


Table 2 UChicago MIP
Project: SMEX/POEMS
Date: 7/24/94

Critical | Progress | Summary
Noncritical | Milestone | Rolled Up

ID	Name	Duration
116	**4 MAGNET**	305d
117	**4.1 Mag. & bore anti prototype**	130d
118	**4.1.1 Magnet**	130d
119	4.1.1.1 Magnet design	55d
120	4.1.1.2 Prototype construction	20d
121	4.1.1.3 Magnet measurements	20d
122	**4.2 FM mag. & bore anti**	305d
123	**4.2.1 FM Magnet design**	174d
124	4.2.1.1 Magnet design phase 1	30d
125	4.2.1.2 PDR	0d
126	4.2.1.3 Magnet design phase 2	30d
127	4.2.1.4 CDR	0d
128	4.2.2 Magnet material delivery	90d
129	**4.2.3 FM Bore anti design**	140d
130	4.2.3.1 Bore anti design	40d
131	4.2.3.2 Procure material	80d
132	4.2.3.3 Bore anti testing	20d
133	**4.2.4 Magnet development**	65d
134	4.2.4.1 Magnet construction	30d
135	4.2.4.2 Magnet testing	10d
136	4.2.4.3 Mag. / bore/ anti Integration	10d
137	4.2.4.4 Environmental testing	5d
138	4.2.4.5 Deliver subassembly to U/C	10d
139	4.3 Flight mag. ass'y	0d
140	4.4 Flight protoflight mag. ass'y	0d
141		

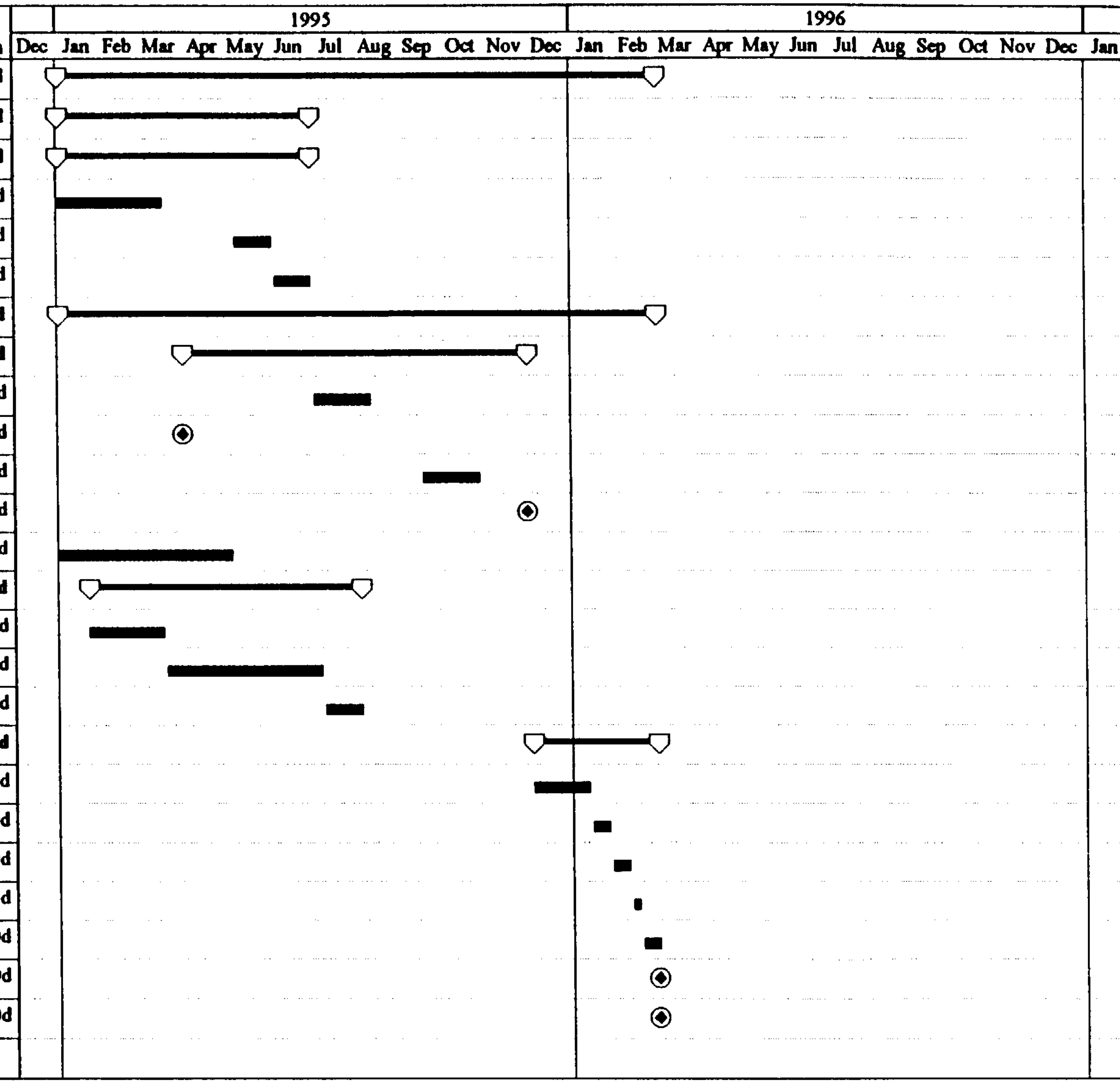


Table 2 UChicago MIP
Project: SMEX/POEMS
Date: 7/24/94

Critical — Progress — Summary
Noncritical — Milestone — Rolled Up

ID	Name	Duration
142	**5 DETECTOR SUBASSEMBLY "B"**	460d
143	**5.1 Detector "B" fabrication**	460d
144	5.1.1 Design prototype mag. housing GSFC	65d
145	5.1.2 U/C Fabricate magnet test frames	17d
146	5.1.3 Fabricate magnet flight frames	30d
147	5.1.4 Deliver frames to U/T	10d
148	5.1.5 Receive protoflight/flight magnet at U/C	0d
149	5.1.6 Test fit protoflight/flight mag.	3d
150	5.1.7 Install protoflight magnet on sim.S/C plate	3d
151	5.1.8 Ship flight magnet to GSFC	3d
152	5.1.9 Integrate and test mag.and det. at GSFC	147d
153	5.1.10 Deliver subsystem" B" to U/C	4d
154	5.1.11 Receive and test	5d
155	5.2 PDR U/T GSFC U/C	0d
156	5.3 CDR U/T GSFC U/C	0d
157		

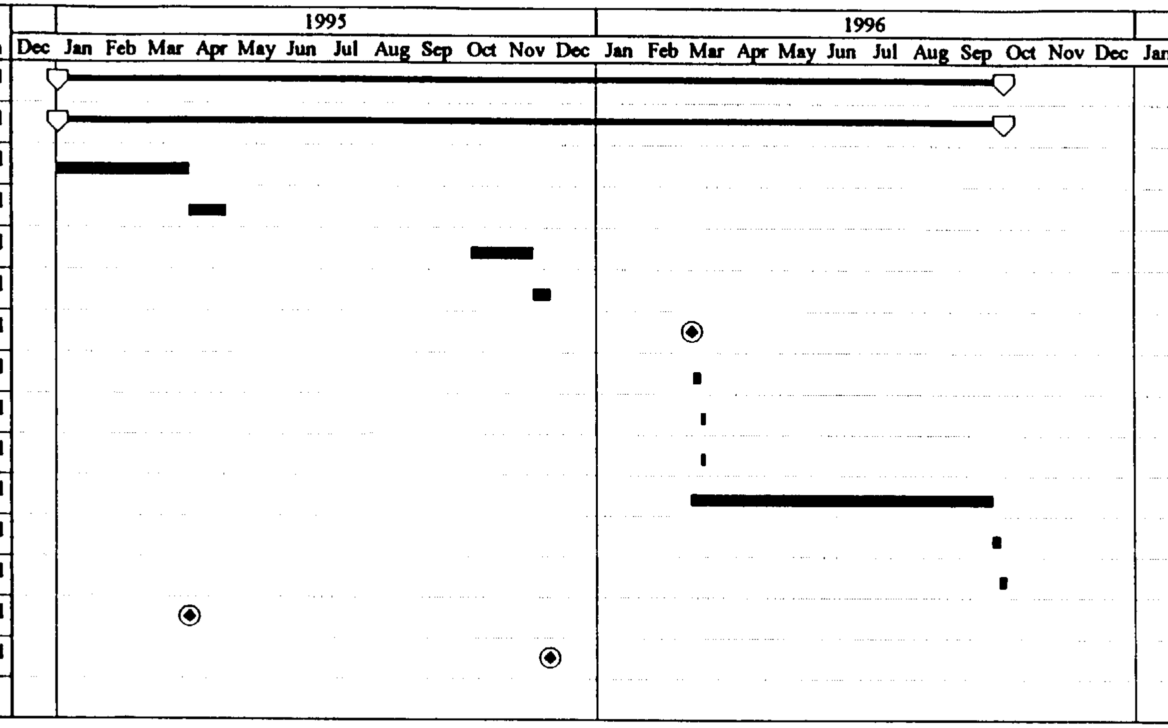


Table 2 UChicago MIP
Project: SMEX/POEMS
Date: 7/24/94

Critical — Progress — Summary — Noncritical — Milestone — Rolled Up

ID	Name	Duration
158	**6 DETECTOR SUBASSEMBLY "C"**	370d
159	**6.1 CsI prototype (D4)**	52d
160	6.1.1 Design CsI crystal	10d
161	6.1.2 Design mock CsI crystal	2d
162	6.1.3 Design prototype housing	10d
163	6.1.4 Fabricate CsI stack	15d
164	6.1.5 Qualify prototype assembly	15d
165	**6.2 Subassembly " C"**	360d
166	6.2.1 Design box anti (D5)	20d
167	6.2.2 Design D3/D6 counter	10d
168	6.2.3 Design CsI Stack (D4)	10d
169	6.2.4 Design subsystem "C" hardware	20d
170	6.2.5 Procure CsI crystals	100d
171	6.2.6 Receive & inspect CsI crystals	10d
172	6.2.7 Assemble CsI crystals	15d
173	6.2.8 Install CsI crystals	5d
174	6.2.9 Procure scintillators	1d
175	6.2.10 Receive scintillators	100d
176	6.2.11 Fabricate scintillators	60d
177	6.2.12 Procure housing material	10d
178	6.2.13 Receive aluminum & test mat'l	5d
179	6.2.14 Fabricate all mech. hardware	60d
180	6.2.15 Procure photodiodes	3d
181	6.2.16 Receive and test photodiodes	10d
182	6.2.17 Install photodiodes/ crystals	15d
183	6.2.18 Assemble stack	10d
184	6.2.19 Assemble box (D5) anti scintillators	20d
185	6.2.20 Assemble D3/D6 detector	15d
186	6.2.21 Assemble enclosures	15d

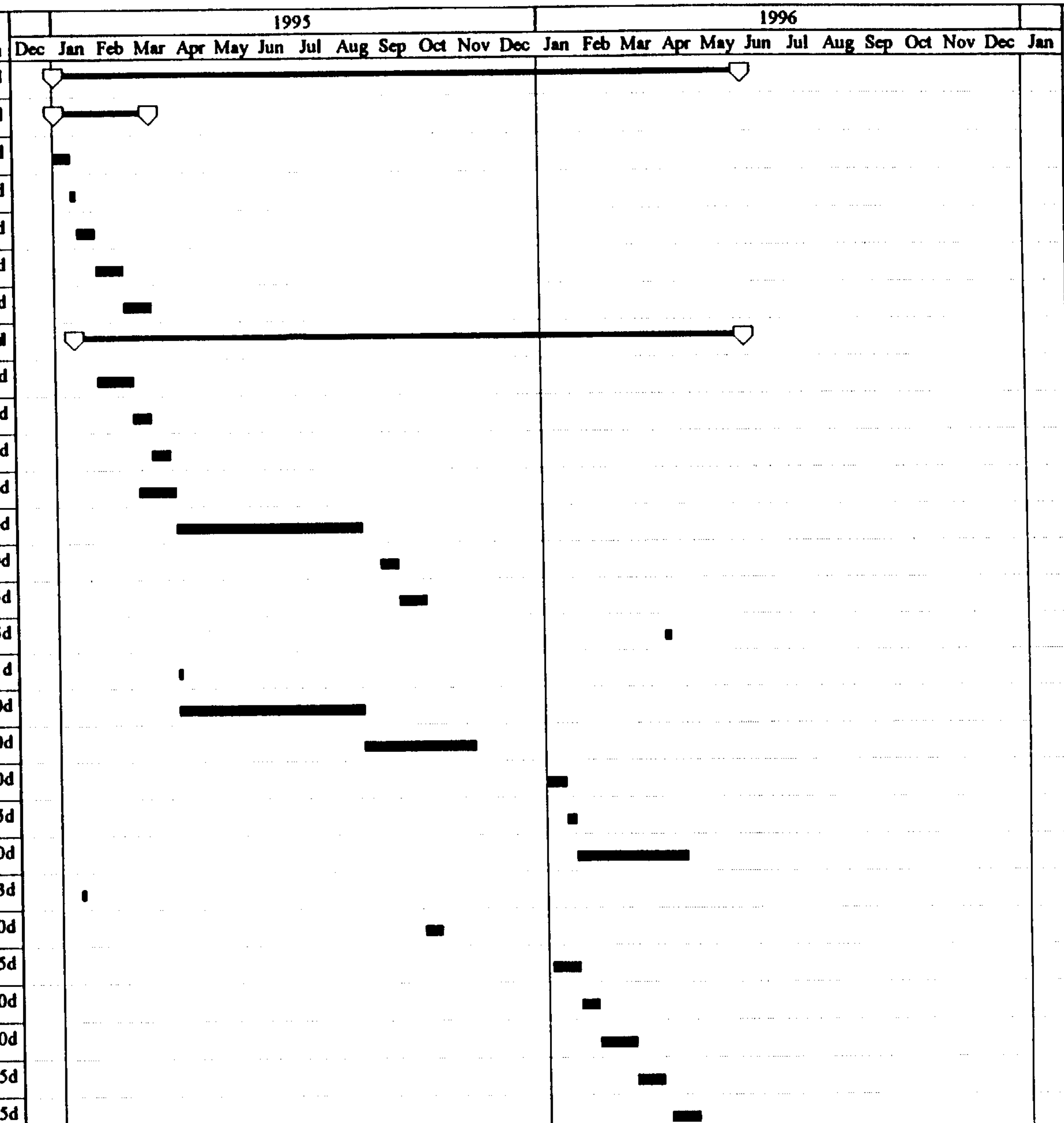


Table 2 UChicago MIP
Project: SMEX/POEMS
Date: 7/24/94

Critical
Noncritical
Progress
Milestone
Summary
Rolled Up

ID	Name	Duration
187	6.2.22 Install PMT's	5d
188	6.2.23 Bench test	5d
189	6.2.24 Begin qualification testing	20d
190	6.2.25 Deliver subsystem "C"	0d
191	6.3 PDR	0d
192	6.4 CDR	0d
193		

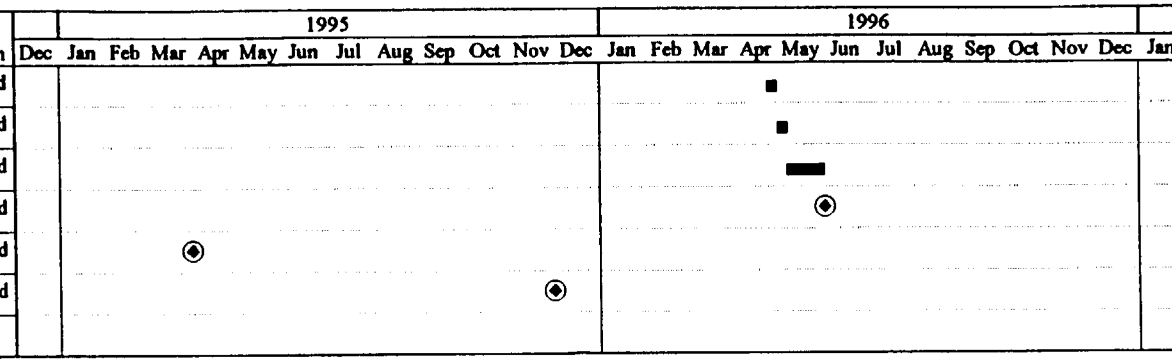


Table 2 UChicago MIP
Project: SMEX/POEMS
Date: 7/24/94

Critical — Progress — Summary
Noncritical — Milestone — Rolled Up

ID	Name	Duration
194	**7 POEMS S/C BRACKET SUBASSEMBLY "G"**	**282d**
195	7.1 Design S/C connector bracket	10d
196	7.2 Fab. connector bracket	10d
197	7.3 Assemble subassembly "G"	10d
198	7.4 Deliver subassembly "G" to U/C	0d
199		
200	**8 INTEGRATION SUPPORT**	**157d**
201	8.1 Design simulated S/C plate	10d
202	8.2 procure material	1d
203	8.3 receive & inspect mat'l	10d
204	8.4 Fab. simulated S/C plate	5d
205	8.5 Design POEMS shipping container	10d
206	8.6 procure shipping container	5d
207	8.7 Receive shipping container	60d
208	8.8 Fit check S/Cplate into container	5d
209		
210	**9 SUBASSEMBLIES DELIVERY TO U/C**	**96d**
211	9.1 Deliver subassembly "A" to U/C integration	0d
212	9.2 Deliver subassembly "B" to U/C integration	0d
213	9.3 Deliver subassembly "C" to U/C integration	0d
214	9.4 Deliver subassembly "D" to U/C integration	0d
215	9.5 Deliver subassembly "E" to U/C integration	0d
216	9.6 Deliver subassembly "F"to U/C integration	0d
217	9.7 Deliver subassembly "G" to U/C integration	0d
218		

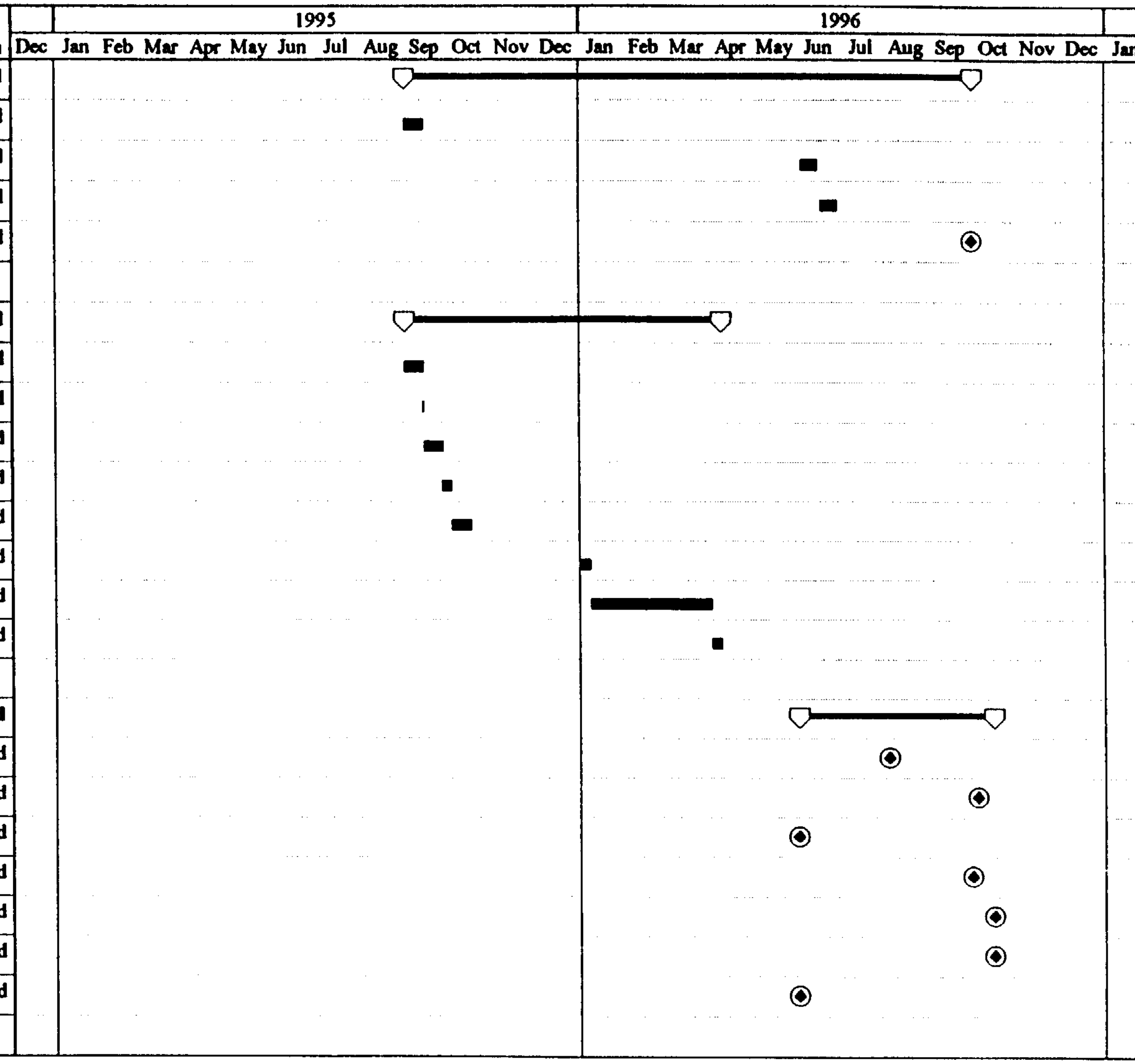


Table 2 UChicago MIP
Project: SMEX/POEMS
Date: 7/24/94

Critical
Noncritical
Progress
Milestone
Summary
Rolled Up

ID	Name	Duration
219	**10 INTEGRATION**	**23d**
220	**10.1 S/C sim for MS**	**16d**
221	10.1.1 Integrate A to S/C sim	2d
222	10.1.2 Integrate protoflight B to S/C sim	2d
223	10.1.3 Integrate C to S/C sim	2d
224	10.1.4 Integrate D to S/C sim	2d
225	10.1.5 Integrate G to S/C sim	2d
226	10.1.6 Initial Power & Function test	5d
227	10.1.7 Comprehensive Performance Test	7d
228	**10.2 S/C plate**	**9d**
229	10.2.1 Transfer MS to S/C plate	2d
230	10.2.2 Integrate E to S/C plate	2d
231	10.2.3 Integrate F to S/C plate	1d
232	10.2.4 Integrate G to S/C plate	2d
233	10.2.5 Comprehensive performance test	5d
234		

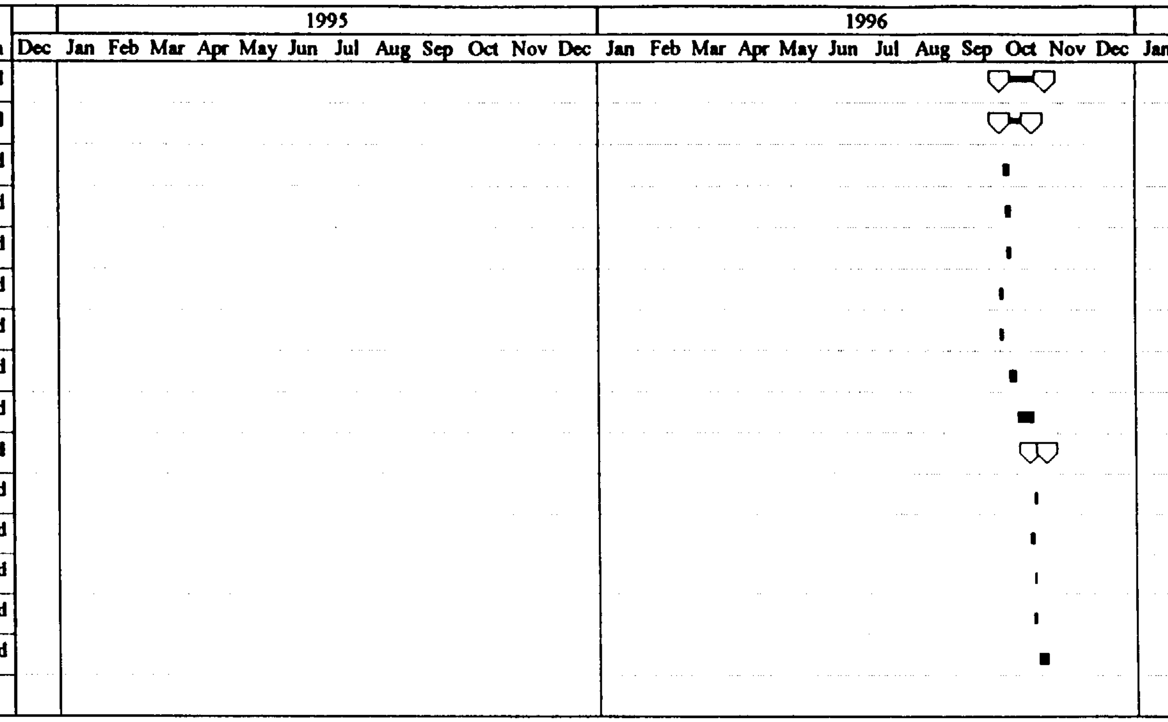


Table 2 UChicago MIP
Project: SMEX/POEMS
Date: 7/24/94

Critical
Noncritical
Progress
Milestone
Summary
Rolled Up

ID	Name	Duration
235	**11 ENVIRONMENTAL TESTS**	**41d**
236	11.1 Mass Properties	1d
237	**11.2 Vibration Series**	**10d**
238	11.2.1 Travel	1d
239	11.2.2 Pre Vibration CPT	1d
240	11.2.3 Sine Survey	2d
241	11.2.4 Random	3d
242	11.2.5 (Shock) Sine Burst	2d
243	11.2.6 Post Vib/ Pre EMI CPT	1d
244	**11.3 EMI**	**8d**
245	11.3.1 EMI Preps	1d
246	11.3.2 EMI Tests	5d
247	11.3.3 Travel	1d
248	11.3.4 Post EMI CPT	1d
249	**11.4 Acoustic Test**	**5d**
250	11.4.1 Travel	2d
251	11.4.2 Pre Acoustic CPT	1d
252	11.4.3 Acoustic Test	1d
253	11.4.4 Post Acoustic/ Pre Magnetic CPT	1d
254	**11.5 Magnetic Test**	**4d**
255	11.5.1 Magnetic Test	1d
256	11.5.2 Post Magnetic CPT	1d
257	11.5.3 Travel	2d
258	**11.6 Thermal Vacuum Test**	**12d**
259	11.6.1 TV Test Preps	1d
260	11.6.2 Pre TVT CPT	1d
261	11.6.3 TV Test	7d
262	11.6.4 Travel	3d
263	11.6.5 Post TV Test CPT	1d

Timeline: 1995 (Dec, Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec), 1996 (Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec, Jan)

Table 2 UChicago MIP
Project: SMEX/POEMS
Date: 7/24/94

Critical | Progress | Summary
Noncritical | Milestone | Rolled Up

Appendix 1 - UC SAIP

SAIP SUBMITTED SEPARATELY

WITH PAIP (DOC# BRI-SMEX-011)

Appendix 2 - UC MS Thermal report for phase I

Ball System Engineering Report

	REPORT NO.		DATE 29 June 1994
PROJECT	POEMS		
TITLE	Internal Instrument Thermal Model Report		
PREPARED BY Leslie Buchanan	6/29/94	APPROVED BY Bob Poley	

SCOPE/TEXT: (ATTACH ADDITIONAL SHEETS AS REQUIRED)

This report documents the thermal model and preliminary analysis for the Positron Electron Magnetic Spectrometer (POEMS). In the report, we have included descriptions of the preliminary thermal design and thermal model, case descriptions, transient results, and results from a parametric study. We concluded that the preliminary thermal design is workable, and recommended steps for further analysis. We described the hard copy of the thermal model that we are sending on a 3.5 inch floppy disc.

Skip Jensen-Univ. of Chicago
Jacques L'Heureux-Bartol Research Institute (Report only)
Stew Glazer-GSFC

THERMAL DESIGN

In the current thermal design the Magnetic Spectrometer (MS) consists of three components that are thermally isolated from each other. These are the Cerenkov, the hodoscope, and the calorimeter. The Cerenkov and the calorimeter are hard mounted to the spacecraft upper deck using four .25 inch bolts each. The hodoscope is conductively isolated from the s/c. Its temperature is independently controlled by a space radiator located on the anti-sun side of the hodoscope electronics box. All three components are covered in their own MLI blankets. In this thermal model, all of the exterior surfaces of the MS except the radiator are assumed to be adiabatic.

THERMAL MODEL

The node breakdown for the thermal model is shown in Figure 1. In all three sections, node breakdowns were chosen to represent the presence of PMT's. Assuming good thermal conductance at the mounting interface, PMT temperatures are represented by the temperatures of the underlying structure.

The Cerenkov was modelled with 14 nodes. It was broken down into quadrants to facilitate the presence of the PMT's. There is also a node for the bottom pressure window so that the radiation heat transfer between the Cerenkov and the hodoscope can be conveniently added to the model in the future.

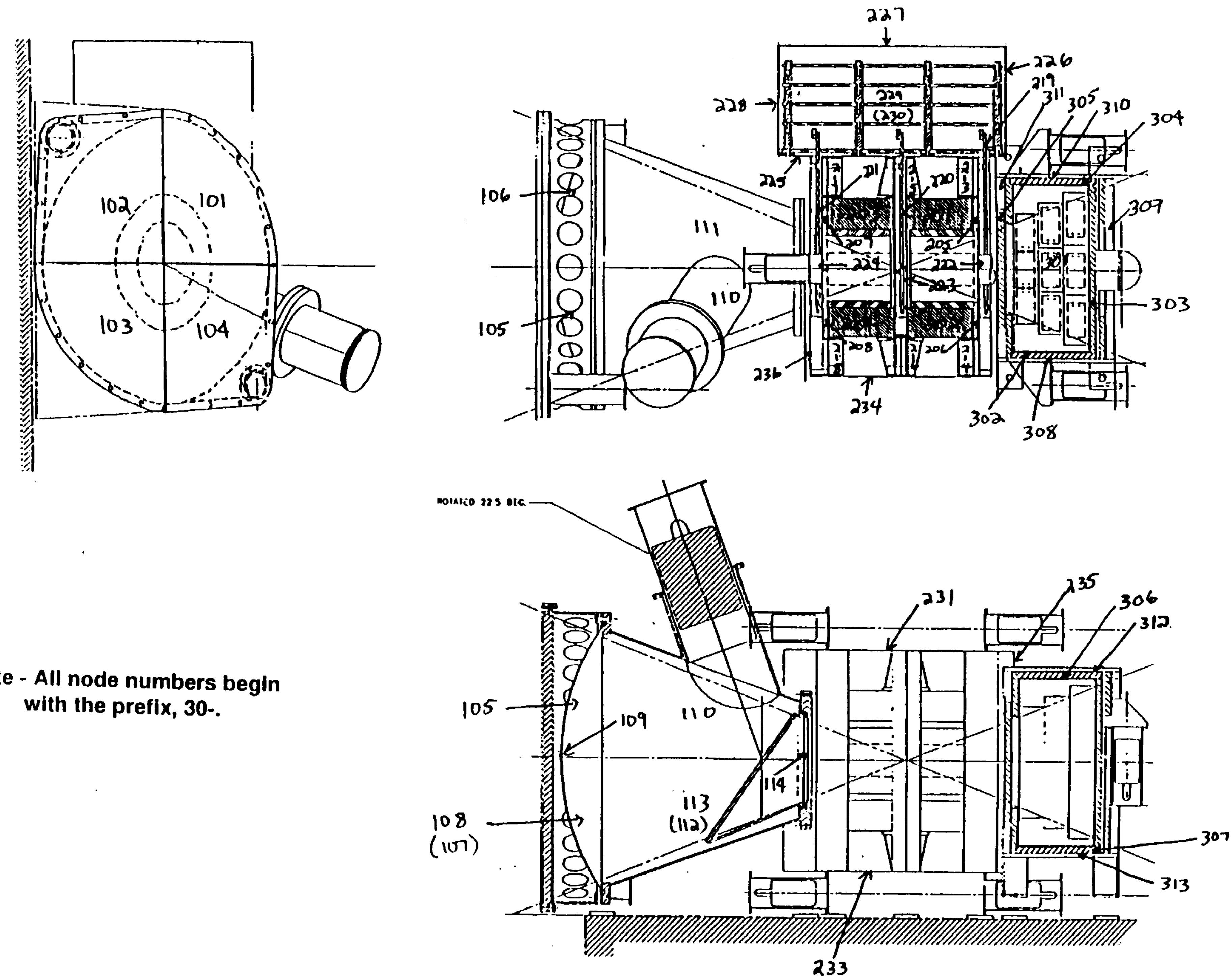
Most of the modelling detail was concentrated in the hodoscope. The magnet assembly was halved vertically along the centerline to model the gradients caused by the presence of the radiator on the anti-sun side of the hodoscope electronics. The interface resistance between the magnet frames, scintillators, and magnets is assumed to be negligible. The electronics were modelled to the box level. The box is assumed to have good thermal contact with the magnet frames. For the detector assembly, the detectors are assumed to be made of Aluminum plated Silicon, and are bonded to PC boards. The PC boards are then bolted to Aluminum racks with 7 #4 bolts. The racks are assumed to have good thermal contact with the magnet frames along their side edges. Radiation exchange between the detectors and the bore anti scintillators was modelled. The detectors were assumed to have oxidized Aluminum finishes with ε = .2, and the scintillators had ε = .8. The hodoscope cover plates were included in the model to facilitate the addition of radiation conductors through external MLI blankets. For this preliminary model, 100 % of the area available for the radiator was used. The radiator was assumed to be painted with S13G/LO white paint.

Thirteen nodes were used to model the calorimeter. There is one node for the Cesium Iodide array, and nodes representing each side of the scintillator and housing.

A node list is included in Table 1. The list contains node numbers, descriptions, materials, masses, and properties. Masses were obtained from the University of Chicago Weight Tabulation dated 6/13/94.

ANALYSIS CASES

The model was used to analyze a worst hot operate and a worst cold operate case. The parameters that were varied to create these cases are listed in Table 2. The environmental parameters were obtained from the thermal section of the GSFC Poems System Requirements Review presentation dated June 2, 1994. The electrical power was obtained from the University of



Note - All node numbers begin with the prefix, 30-.

Figure 1. Node Breakdown

Table 1. Node List

Node Number	Description	Material	Mass (g)	Specific Heat (J/g K)	Thermal Conductivity (W/cm K)
Cerenkov					
30101-30104	Top Cover				
	-Scintillator Housing and Flange	Al 6061	199.7	0.962	1.71
	-Scintillator	Lexan	75.1	1.25	0.0019
30105-30108	Support Ring	AL 6061	27.4	0.962	1.71
30109	Top Pressure Window	AL 6061	95.3	0.962	1.71
30110-30113	Cone	AL 6061	286.7	0.962	1.71
30114	Bottom Pressure Window	AL 6061	57.3	0.962	1.71
Hodoscope					
30201-30204	Magnets	Nickel/Cobalt Alloy	1236.6	0.42	0.07
30205-30208	Bore Anti Scintillator Covers	Lexan	7.65	1.25	0.0019
30209-30212	Bore Anti Scintillators	Lexan	54.2	1.25	0.0019
30213,30214	Top Magnet Frame	AL 2219	304.9	0.92	1.73
30215, 30216	Center Magnet Frames	AL 2219	182.6	0.92	1.73
30217, 30218	Bottom Magnet Frame	AL 2219	304.9	0.92	1.73
30219-30221	Detector PC Boards	G-10	91.6	1.46	0.0029
30222-30224	Detectors				
	Chip	Silicon	Massless	N/A	1.48
	Plating	AL 6061	Massless	N/A	1.71
30225-30230	Electronics Box	AL 2219	259.7	0.92	1.73
30231-30235	Cover	AL 2219	Massless	N/A	1.73

Table 1 (Continued). Node List

Node Number	Description	Material	Mass (g)	Specific Heat (J/g K)	Thermal Conductivity (W/cm K)
Calorimeter					
30301	Cesium Iodide Array				
	-Crystals	Cesium Iodide	2874.0	0.201	0.0105
	-Al Volume	AL 6061	378.2	0.962	1.71
30302,30304	Side Box Anti				
	-Scintillators	Lexan	56.7	1.25	0.0019
	-Liners	AL 6061	21.6	0.962	1.71
30303	Bottom Box Anti				
	-Scintillator	Lexan	132.4	1.25	0.0019
	-Liner	AL 6061	45.4	0.962	1.71
30305	Top Box Anti				
	-Scintillator	Lexan	92.4	1.25	0.0019
	-Liner	AL 6061	41.7	0.962	1.71
30306,30307	Side Box Anti				
	-Scintillators	Lexan	52.6	1.25	0.0019
	-Liner	AL 6061	21.6	0.962	1.71
30308,30310	Side Scintillator Housing	AL 6061	281.7	0.962	1.71
30309	Bottom Scintillator Housing	AL 6061	413.4	0.962	1.71
30311	Top Scintillator Housing	AL 6061	101.6	0.962	1.71
30312	Side Scintillator Housing	AL 6061	320.0	0.962	1.71
30313	Side Scintillator Housing	AL 6061	132.4	0.962	1.71

Table 2. Case Descriptions

Parameter	Hot Operate Case	Cold Operate Case
Solar Constant (W/m^2)	1419.0	1286.0
Albedo	0.35	0.25
Earth IR (W/m^2)	265.	208.
Beta Angle (Degrees)	50.0	90.0
Spacecraft Upper Deck Temperature (°C)	23.0	6.0
Total Electrical Power (W)	5.72	5.72
S13G/LO White Paint -absorptance -emittance	 0.30 0.88	 0.20 0.88

Chicago. The power dissipation is the same in both cases because the cold case power breakdown was not yet available. Properties for the white paint are from LDEF.

RESULTS

Transient temperatures during orbit for the hot and cold cases are shown in Table 3. A margin for uncertainty has not been added to these temperatures.The Cerenkov and the calorimeter follow the temperature of the s/c upper deck due to their low power dissipations. The hodoscope components experience a small temperature variation in the hot case. With a beta angle of 90 ° in the cold case, Albedo heating on the radiator is small so the components remain at steady temperatures. With 100 % of the available area utilized, the hodoscope radiator experiences an overall range of -18.9 to -12.5 °C . This causes the electronics box baseplate to have a range of -7.7 to -1.9 °C. There is a maximum gradient of 0.4 °C across the magnet assembly. As shown in Figure 2, the hot case orbital temperature variation is consistent for all three detectors, with a maximum axial gradient of less than 0.01 °C . The slightly higher gradients that exist between the detectors and their support structure remain consistent throughout the orbit as well, as shown in Figure 3. The detectors have an overall range of -6.0 to -0.2 °C.

PARAMETRIC STUDY

From the analysis we determined that the hodoscope electronics and detectors may be running on the cool side of their acceptable ranges when 100 % of the available radiator area is used. As an aid in sizing the radiator, we performed a radiator size parametric study. Results from the study are provided in Figures 4 and 5. The figures show the variation in the steady state temperatures of the detector, electronics baseplate and radiator as the radiator size is increased from 75 % to 100 % of the available area for the hot and cold cases.

Table 3. Orbital Temperature Variation (°C)

Component	Hot Operate Case MIN	Hot Operate Case MAX	Cold Operate Case
Cerenkov	23.0	23.0	6.0
Hodoscope			
-Detectors	-0.3	-0.2	-6.0
-Detector PC Boards	-0.3	-0.2	-6.0
-Magnet Assembly, Non-Radiator Side	-1.0	-0.9	-6.7
-Magnet Assembly, Radiator Side	-1.3	-1.3	-7.1
-Cover	-1.2	-1.1	-6.9
-Electronics Box Baseplate	-2.0	-1.9	-7.7
-Electronics Box Walls	-7.7	-7.3	-13.3
-Electronics Box Radiator	-13.4	-12.5	-18.9
Calorimeter	23.0	23.0	6.0

CONCLUSIONS AND RECOMMENDATIONS

Results from the analysis show that the preliminary thermal design for the MS is workable. The gradients throughout the instrument are small, and there is plenty of radiator surface area available for maintaining the temperature of the hodoscope. By locating the radiator on the anti-sun side of the spacecraft, the temperature variations during orbit are small.

To complete the analysis, it is recommended that this internal model be incorporated into the overall s/c model which includes the heat transfer through the MLI on the external surfaces, the minimum powers be incorporated into the cold operate case, and the hodoscope radiator be re-sized to achieve optimal temperatures.

MODEL HARD COPY DESCRIPTION

We have included a hardcopy of the steady state, hot and cold operate thermal models on the accompanying 3.5 inch floppy disc. The filenames are POEMSH.SIN and POEMSC.SIN, respectively. The models have been converted from TAKIII to SINDA85 format. They include an in-house subroutine called QFLUX to automatically interpolate and apply the flux arrays. We have assumed that GSFC has a similar subroutine and can replace our call with one of their own. For clarity, we have included a description of our QFLUX subroutine in Appendix A.

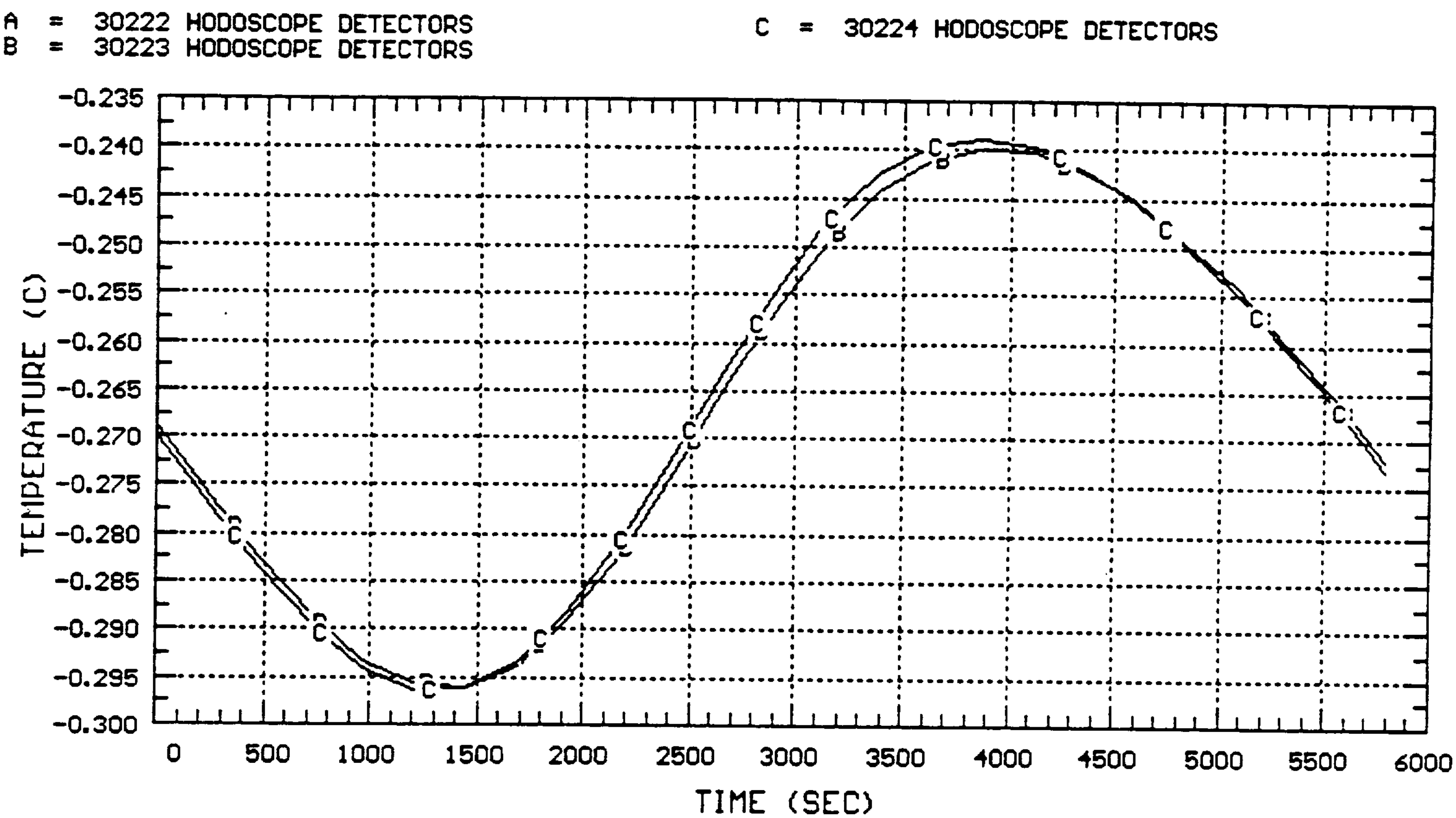


Figure 2. Detector Orbital Temperature Variation - Hot Case

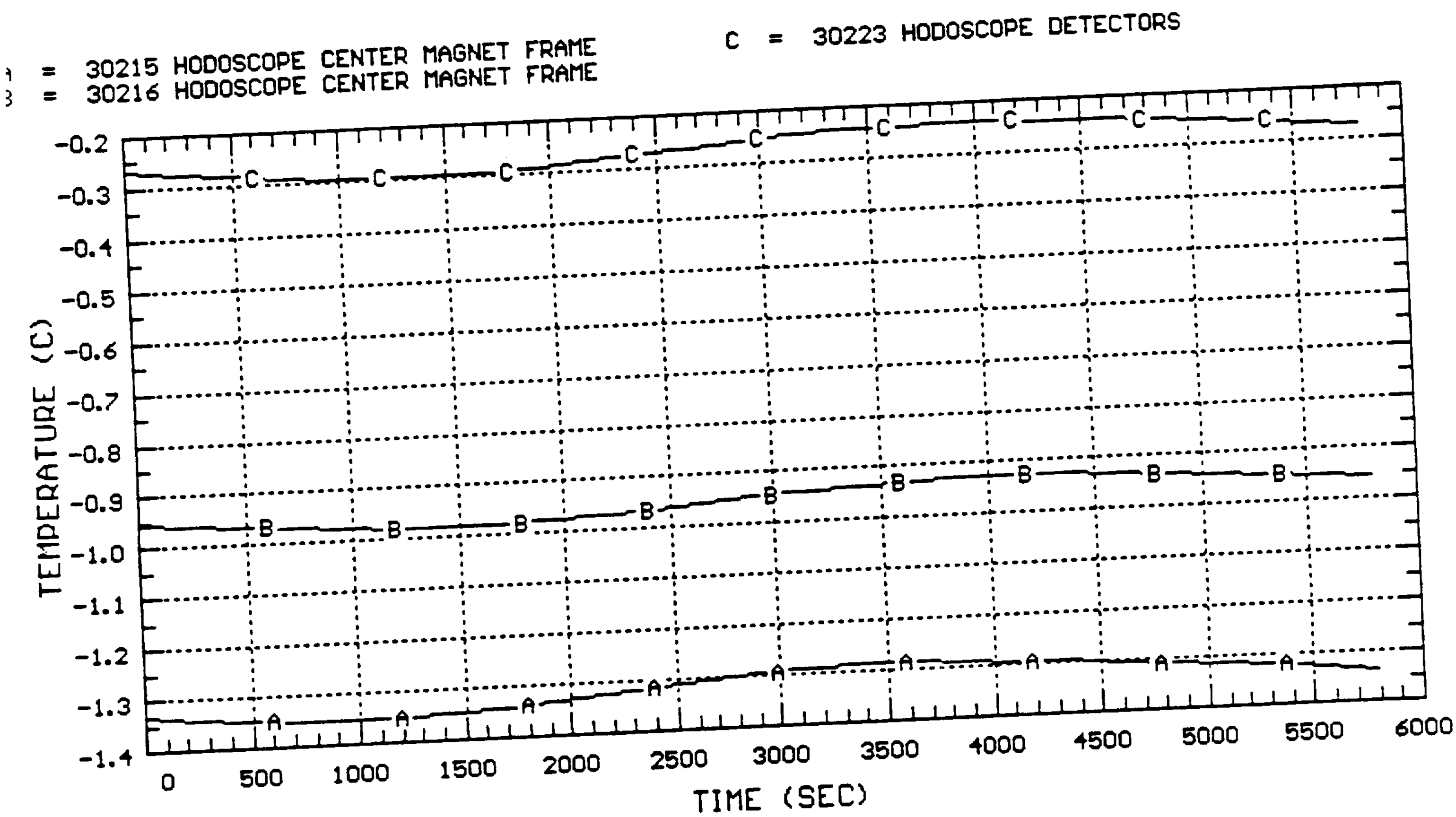


Figure 3. Detector/Frame Orbital Temperature Variation - Hot Case

Figure 4. Radiator Size Parametric Study - Steady State Hot Case

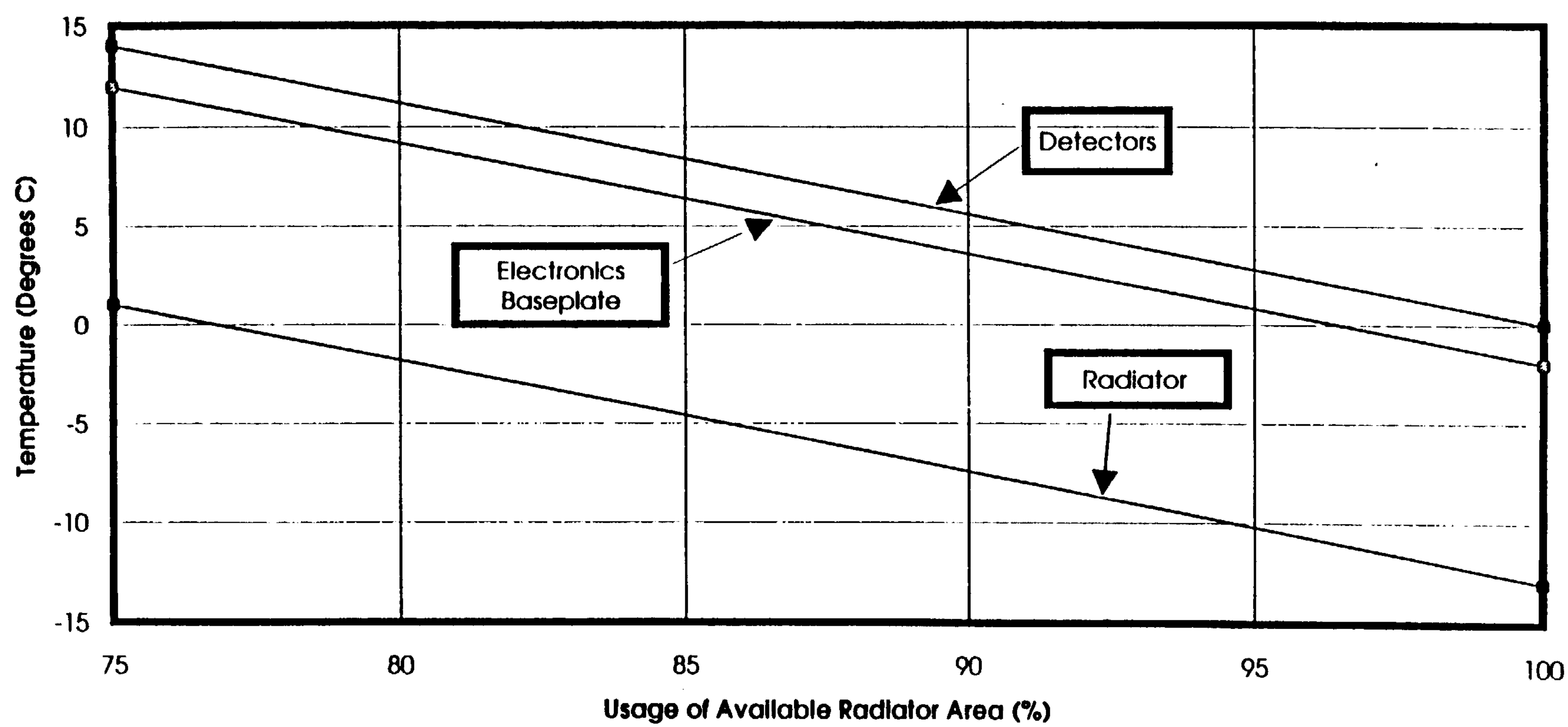
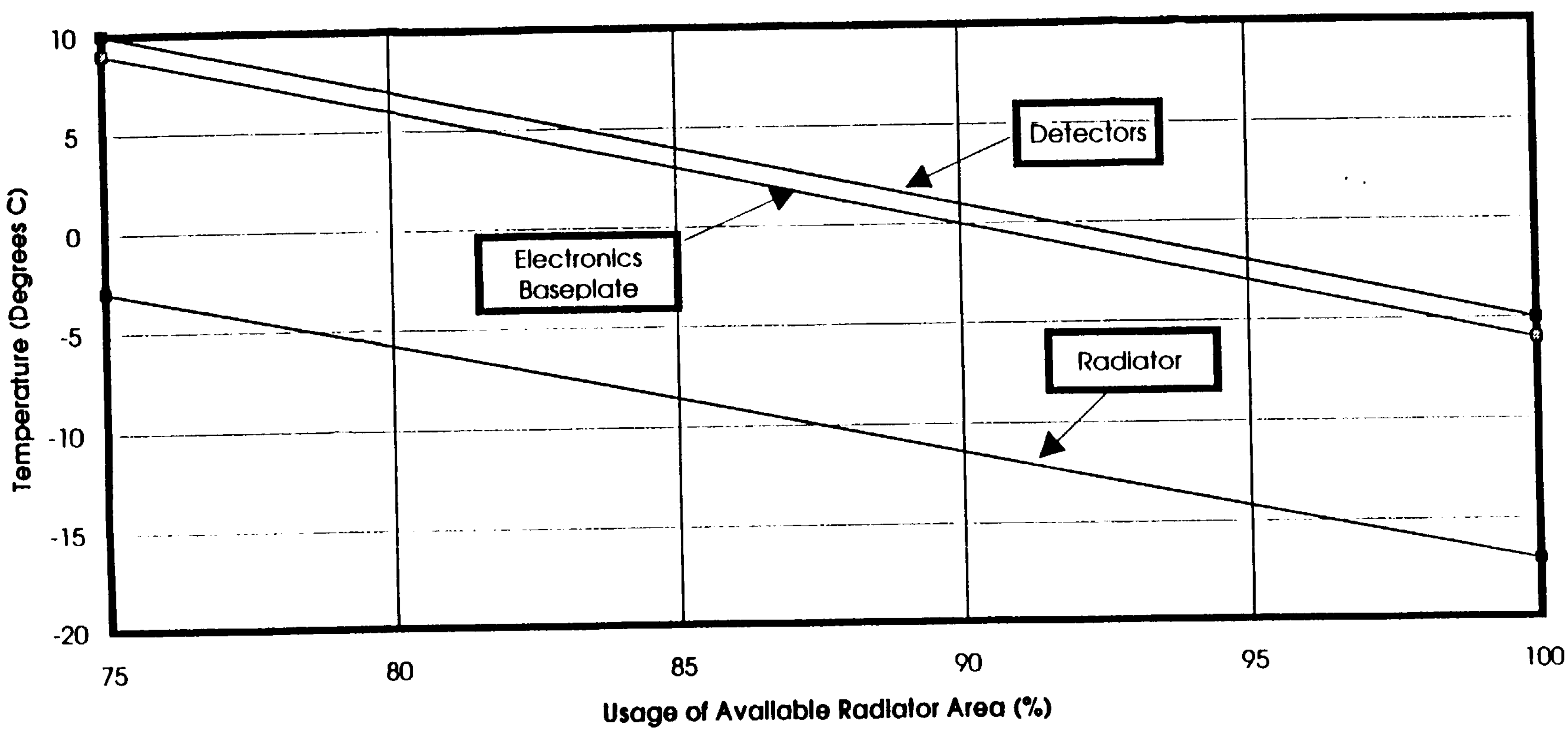


Figure 5. Radiator Parametric Study - Steady State Cold Case



APPENDIX A

Subroutine QDUMP

This subroutine will compute and write out the thermal network map along with a heat flow map based upon the current nodal temperatures and conductance values. This routine is very similar to the SINDA'85 subroutine QMAP.

QDUMP (and QMAP) is extremely useful for two reasons. First, when a model is first built, nine times out of ten there is usually a mis-connected node or nodes. It is important to weed these out as soon as possible so it is recommended that the analyst run this routine during early model development. Second, the analyst usually needs to understand where the heat is flowing to and from. Since this routine prints out individual heat flows and percentage of total this job is made much easier. An lastly, QDUMP will report the node with the maximum energy imbalance.

Restrictions:

Because of the volume of output, QDUMP should only be called in the OPERATIONS DATA block.

Calling Sequence:

```
CALL QDUMP( 'SMN' )
```

where:

SMN = any active thermal sub-model name or 'ALL' for all sub-models

The following is an example of a QDUMP output.

```
-------------------------------------------------------------------------------------------------------
                                                                        Temp.       MCp        CSG
Node    Model     Type                  Node Description              ----------  ----------  ----------
------  --------  ----------  -------------------------------------     -0.830     10.0000    0.488E-01
  1002  CNDSER    Diffusion   Condenser Wall Section #2

Connected to:                                                        Cond.   Type      Value       Qdot      % Total
Node      Model       Temp.       Description                        ------- --------  ----------  ----------  -------
------  --------  ----------  ---------------------------------------    10  LINEAR    0.503E-02   0.523E-03   40.05
  1001  CNDSER         9.555  Condenser Wall Section #1                  11  LINEAR    0.503E-02  -0.195E-03  -15.25
  1003  CNDSER        -4.785  Condenser Wall Section #3                  21  LINEAR    0.104E-03  -0.583E-03  -44.71
  2000  CNDSER        -6.424  Radiator Panel

Linear Qdot =  -0.2598E-03    Radiation Qdot =  0.0000E-00   Heat sources/sinks =  0.2598E-03   Net Balances =  0.3867E-01
-------------------------------------------------------------------------------------------------------
```

Subroutine QFLUX

This subroutine will apply orbital timelined fluxes into the appropriate Q-source location for any/all thermal sub-models. With this one call, the user defined flux tables are automatically interpolated and the resulting heating rates added to the Q-source locations. This eliminates the need for the a D1D1DA call for each flux table.

QFLUX will automatically calculate orbital average flux rates if the user is running a steady state routine. This eliminates the need to have two sets of heating rates; one for steady state and one for transient.

Restrictions:

There must be a "time" array defined followed by any number of flux arrays. The number of orbital flux positions must match the number of times in the time array. The following is the format that should be used.

HEADER ARRAY DATA, SMN

N S time array
t1, t2, t2 .... tn
END

N, NODE, MULT S flux array #1
f1, f2, f3 ... fn
END

N, NODE, MULT S flux array #2
f1, f2, f3 ... fn
END

.
.
.

Where:

N = array numbers
t(n) = orbital times
f(n) = flux values that correspond to the orbital times
NOD= Enode where flux should be applied
MULT= flux multiplier

QFLUX should normally be called in VARIABLES 1 data block.
Multiple sets of flux tables can be used. This is done by preceding each set with its own "TIME" array. The user must also have a unique call to QFLUX for each set. The number of orbital positions in one set does NOT have to match any other.

Calling Sequence:

```
M       CALL QFLUX( ' SMN ', ITA, NUM )
```

where:

SMN = Any active thermal sub-model name
ITA = Time array number (integer)
NUM = Number of flux arrays to follow time array (integer)

Subroutine PLOTQ

This subroutine writes out the impressed heating rates for all active nodes to a ".S71" file. This file is the same format that PLOT85 writes so the SINDA'85/FLUINT plotting program XPLOT can be used to plot the heating rates (Make sure you change the x-axis label from temperature to heating rate).

This routine is useful when trying to determine why nodal temperatures are behaving unexpectantly. What it usually uncovers is incorrect heating rates that the analyst as inadvertently applied.

Restrictions:

PLOTQ should normally be called from OUTPUT CALLS for transient runs or the OPERATIONS block for successive parametric steady state runs. It can be called from the other logic blocks.

Current Limits:

Maximum number of thermal sub-models is 5
Maximum number of nodes per model is 500
Maximum number of time hacks is 200

These are limitations of "XPLOT".

Calling Sequence:

```
M       CALL PLOTQ
```

Subroutine QTOT

This subroutine sums and returns the impressed rates to all diffusion and arithmetic nodes in a given sub-model. This routine is handy to verify various heating rates such as electrical dissipation.

Appendix C

Final Report from the
Laboratory for High Energy Astrophysics (LHEA)
of the
Goddard Space Flight Center

POEMS - Phase B
Final Report

Goddard Space Flight Center
Dec. 16, 1994

POEMS Phase B Final Report

Introduction

The Goddard Space Flight Center was responsible for the design and development of the hodoscope subsystem for the POEMS Smaller Explorer Mission. This report is a summary of technical activities during the Phase B study, which lasted from January 1994 through August of 1994.

POEMS was designed as a magnet spectrometer instrument for separating electrons and positrons from ≈ 20 MeV up to ≈ 2 GeV. The separation is accomplished by means of a permanent magnet with a central bore through which the particles pass, and appropriate tracking detectors which determine the particle trajectory through the bore in real space. Post processing of the trajectory determines the curvature and hence the sign of the charge. Other detectors are used to separate background from protons, neutrons, pions, etc. The hodoscope design was baselined to have a spatial resolution of 50 microns in the bending direction (perpendicular to the B field) and 2500 microns in the orthogonal direction (parallel to the B field).

This document summarizes the completed detector and readout electronics design. If another flight opportunity were to arise for an instrument of this approximate mass and power, we would be prepared to fabricate a hodoscope system from these designs.

Prototype Detector

The tracking detectors for POEMS are ion implanted silicon strip detectors (SSD's). These are fairly rugged single crystal wafers sliced from n type silicon of high resistivity. SSDs have been used for many years at accelerators with great success. We have endeavored in the POEMS design to build on this work and adapt this technology for use in space.

A single sided SSD close in design to this prototype was given to us by the Univesity of Oklahoma. In the end, it was to be the only device available to us for our electronics testing.

Specifications for POEMS Prototype

This section provides most of the detailed manufacturing and testing specifications which were developed for the POEMS prototype SSDs.

SCOPE

These specifications (and NASA drawing GC 1490490) will establish the requirements for a prototype spaceflight "n" type silicon, totally depleted, ion implanted, passivated two-dimensional position sensitive detector. The detector will be square, with an active area of ≈26 cm^2, side length of 5.12 cm) and an active thickness of ≈300 microns. This detector must be stable, i.e. have no breakdown, when operated for long durations under spaceflight (i.e. vacuum) conditions. The term prototype is understood to mean that this detector and the materials used shall not be tested to the rigorous enviromental limits imposed on spaceflight hardware. This detector is to be designed for proof of principle, with the understanding that future detectors manufactured for this project will have to meet more rigorous testing standards.

BASIC DESIGN AND POSITION SENSING TECHNOLOGY

The detector is to be made position sensitive by using standard photolithographic techniques for defining strips on each surface of the detector. The length of the strips shall be selected so that the strip ends define a square area of ≈26 cm^2. The junction side of the detector shall be referred to as the front side. Likewise, the ohmic side shall be referred to as the back side. The strips on the front side will have a width of ≈40 microns with an interstrip gap of ≈10 microns, giving a pitch of 50 microns. The rear surface shall have ≈2460 micron wide strips with an interstrip gap of 100 microns, giving a pitch of 2560 microns (2.56 mm). The manufacturer is to optimize the strip width and gap width in order to maximize the interstrip capacitance, keeping in mind the required minimum interstrip resistence of 1 MΩ. The strips on the rear shall be orthogonal to the strips on the front. All strips shall have evaporated aluminum over the implanted areas to facilitate ultrasonic wire bonding.

The front side of the detector mount will be designed to accomodate 4 SVX chips in close proximity to the strip edges. The SVX chip inputs (128 per chip) will be wire bonded to every other strip on the front side of the detector. To accomplish this, the manufacturer will pattern onto the detector a fan-in which brings every alternate strip (100 micron pitch) down to wire bond pads at 50 micron pitch along a single edge of the detector. Each strip connection to the SVX chip input will be accomplished using ultrasonic wire bonding. As a minimum, 99 % of the strips shall be functionally active on the front side with the central 5 cm fully active. The rear side will have 10 outputs from every other strip wire bonded to pads on a side orthogonal to the side on which the SVX chips are connected, and the other 10 outputs bonded on the opposite side. These pads connect the rear strips to the inputs of hybrid preamplifiers. The rear side must have 100 % of the strips active.

The strips on the front and back side will have an oxide covering such that they will be capacitively coupled to the SVX chip inputs and hybrid inputs, respectively. This is to ensure that the normal strip leakage currents will not be seen by the SVX chip inputs. Detector biasing will be supplied thru a separate connection on the mount, and the biasing resistor network for proper detector operation will be incorporated onto the detector as part of the photolithographic and ion implanting process.

The detector will have the following connections for proper operation using four ribbon cables. A single cable to the front side SVX electronics, a connector to the back side hybrid preamplifiers, a connector to the front/back sides for the biasing and for the guard ring operation.

DETAILED SPECIFICATIONS

- Active Area (NASA drawing GC1490490): ≈ 26 cm^2 square.

(The active area is defined by the outside edges of strips 1 and 1024 on the front side and strips 1 and 20 on the back side.)
- The length of a side of the active area = 5.12 cm.
- Front detector channels: 1024;
- Front channel width: 40 ± 1 micron;
- Front channel pitch: 50 ± 1 micron;
- Front interchannel gap: 10 μm ± 1 μm;
- Rear detector channels: 20;

- Rear channel width: 2460 ± 1 microns;
- Rear channel pitch: 2560 ± 1 microns;
- Rear interchannel gap: 100 μm ± 1 μm;
- Front and rear interchannel gap resistance: > 1MΩ;
- Strips on opposite sides are to be orthogonal to < 1°.
- Strips parallel to the side of the mount to ≤ 0.5°.
- Front side must have 99 % good strips and the rear side must have 100%.
- Front side coupling capacitor value ≈ 100 pF;
- Rear side coupling capacitor value ≈ .01 μF;
- A <u>bad strip</u> (front side) is defined for our purposes as:
  - (i) having a shorted coupling capacitor, defined as not able to stand off 2 * Full Depletion Voltage;
  - (ii) having a leakage current > 5 nA.
- A <u>bad strip</u> (rear side) is defined for our purposes as:
  - (i) having a shorted coupling capacitor, defined as not able to stand off 2. * Full Depletion Voltage;
  - (ii) having a leakage current > 50 nA.
- Active Thickness: 300 μm ±15μm.
- Thickness Uniformity: < ± 5 μm.

Operating Bias: The detector's normal operating bias is expected to be 1.5 - 2.0 times the full depletion voltage. A separate bias contact must be available on the test fixture. Bias Voltage for Full Depletion (V_D): ≤ 25 volts.

Leakage Current (Vacuum): <1μA at @ 20°C. The detector's leakage current must be measured with the detector at operating bias and in a vacuum of < 5×10^{-6} torr for at lease 16 hours with all adjacent channels shorted together. The leakage current per strip shall be < 0.5 nA, with a typical value of approximately 0.5 nA. (junction side only)

Equivalent Noise Energy (FWHM): < 25 keV with all adjacent channels shorted together for testing only.

Normal Operating and Test Data Temperature: 20° C ± 2° C.

Detector Operating Environment: The detector is to operate and be long term stable without any type of breakdown over the temperature range of - 40° C to + 5° C at 1 atmosphere or in a vacuum of < 5×10^{-6} torr.

TEST DATA

This is the information we require the manufacturer to supply with each detector:

- Active area;
- Depletion depth at operating voltage;
- Detector current at operating bias using specification 4.6;
- Detector current at operating bias and atmospheric pressure;
- Total system noise width in keV at operating bias;
- Nominal resistivity of silicon wafer;
- Resistance between adjacent strips on front and rear.
- The percentage of functioning strips.
- ^{241}Am alpha particle spectrum.

- Capacitance vs voltage curve and data for the entire detector and for three representative strips.
- Leakage current vs voltage curve and data for the entire detector and for three representative strips.
- Interstrip capacitance measurement for 3 strips on thejunction side of the detector.

MATERIALS

Detectors will be manufactured from silicon wafers manufactured to the following minimum specifications. All other materials are required to meet NASA guidelines for space flight qualification.

- Material: "n" type silicon wafer;
- Wafer thickness: 300 microns ± 15 microns;
- Flatness: ± 5 microns, measured in 5 places across the wafer;
- Taper: ± 2 microns;
- Finish: Lapped and etched both sides with no pits, slurry marks scratches or microcracks.

Status of MICRON Semiconductor Order

At the start of the Phase B study, in January 1994, an order for a prototype SSD meeting the above specifications was sent to MICRON Semiconductor Ltd. of London, England. They were known to us a vendor of reliable silicon detectors. The delivery date was May 1994, which would have given us some time to fully test the device before the end of the study phase. The cost of this prototype was ≈ $35000.

Unfortunately, MICRON is a very small company, and was heavily overcommitted in its work obligations during this year. As a result, they did not deliver a prototype in 1994. Conversations with them have been strained, but they were to have as a minimum finalized the layout design by the end of 1994. This was also not completed. As a result of their inability to deliver us a detector, we decided to seek out alternate suppliers.

Alternate Venders

CSEM

CSEM (Centre Suisse d'Electronique et de Microtechnique) is a Swiss laboratory which was known to be making SSDs for high energy physics projects at CERN (the European Center for Nuclear Research). We contacted them in July about the POEMS prototype and provided them with the same specifications we had supplied MICRON. They indicated they were interested in our project, and three people from the Goddard Solid State Device Development Branch visited CSEM in August. They were very impressed with the facilities of CSEM and highly recommended we proceed.

In this case, we were hurt by the fact that CSEM is a very large laboratory. They subsequently informed us that they would only produce detectors in batches of 25. They would not do just one prototype device. This drove the cost up well beyond our reach, to ≈ $150000.

Surisys Mesures

Surisys Mesures is a French company which was formerly a subsidiary of INTERTECHNIQUE, which was already known to us. In November we approached Surisys Mesures about the POEMS project. They were quite interested also, and said they would certainly do small, unique devices as we wished. In mid November, the device specifications were sent to them for study. Currently we have not received a price quotation.

Goddard Space Flight Center

We also asked the Goddard Space Flight Center solid state device development laboratory to fabricate a prototype SSD as well. Their main emphasis in the past had been on infrared and x-ray detectors, and they in fact had little experience with silicon devices. They undertook this task and devoted quite a bit of their own resources to this project. Starting from "ground zero" they designed and fabricated several devices for us. Unfortunately, because of inexperience in fabrication and poor handling procedures, many problems were encountered (some devices were contaminated because of a lack of surface passivation, some of the etching rates proved hard to control at first, and some of the early oxides were found to be leaky). As a result, none of these first SSDs met our specifications for noise performance and maximum leakage current allowed. They have very recently given us a new device which they believe has solved several of the preceeding errors. This new device is currently under test.

Electronics Development

The silicon detectors for POEMS have a large number of readout channels on the junction side of the detectors (1024 per SSD) which necessitates a sophisticated readout system. Going back to the original POEMS concept developed for the NASA EOS Mission, we elected to base our design around the LBL developed Silicon Vertex Chip (SVX).

The POEMS Magnet Spectrometer electronics consists of eight printed circuit boards - three Hodoscope planes, an interconnecting backplane, an analog Hodoscope Controller (HC) board, a digital HC board, a Back-Side Electronics (BSE) analog board, and a BSE digital board. The Analog to Digital and Digital to Analog Converter circuitry is conventional in design and is not described here. For more details on any aspect of the electronics, one may consult the Goddard Space Flight Center Implementation Plan, submitted to the SMEX Project office at the end of Phase B.

Junction Side Readout

The boards which house the active SSDs themselves are referred to as Hodoscope boards. The Hodoscope boards are three identical 14 layer printed circuit boards. Each of these boards holds one 2" x 2" double-sided 300μ thick detector, four full-custom SVX VLSI readout ICs for the junction side of the detector, two custom-designed hybrids for the ohmic side readout, bias circuitry, power decoupling, and four connectors to provide the system interconnects to the backplane.

The printed circuit board (PCB) is 3.5" x 5.1" including the area of the detector. The maximum board height of 0.18" necessitates the use of surface mount components on this board. Due to board space limitations, the charge terminating capacitors for the hybrid are built into two of the internal layers of the PCB. Power and ground planes are utilized for noise suppression and EMI control. Separating power and ground planes by only 0.005" in the board stackup enables the planes to double as low inductance decoupling capacitors. An effort has been made to specify all dielectric and copper thicknesses in order to make use of microstrip techniques and maximize board performance.

SVX Chip

The SVX VLSI chips are full-custom mixed signal CMOS ASICs, originally developed at the Lawrence Berkeley Laboratory (LBL) for use at Collider Detector Facility (CDF) at Fermilab. Each SVX is capable of providing 128 channels of charge integration, sample and hold, and multiplexed readout. The pitch on the inputs of the SVX chip is 48μ, ideal for the POEMS detectors which are on a 50μ pitch. Four SVX chips will be required to read out the 512 channels for each of the detector planes. Each detector will have 1024 strips and every other strip will be read out.

The charge gain on the SVX is approximately 15mv/fC, and our design provides a dynamic range of up to 50 fC. The expected minimum ionizing pulse (MIP) for the POEMS SSD is 4 fC, producing a signal out of the SVX of approximately 60mV. The SVX chip has an open loop gain of approximately 2000 and a charge integrator feedback capacitance of 0.3 pF, providing an dynamic effective input capacitance of about 600 pF. For the junction side of the POEMS SSD, it is estimated that the S/N ratio will be ≈ 12.

The SVX has multiple modes of operation. The data bus is bi-directional. The control signals for switching the SVX into various operational states and the chip id are inputs; chip id and channel address are multiplexed out.

Each SVX is controlled via fifteen digital signals. A Field Programmable Gate Array (FPGA) directly controls thirteen of these control lines. The SVX has two write modes and two read modes. The write modes are used to set the Neighbor Enable mode on/off, the latch direction (for collecting hole or electrons), load the chip identification, enable or disable the latch all mode, and to control the seven FET switches on each SVX linear chain. The read modes are used to read back the latch all, neighbor enable, and latch direction status bits, and the chip and channel identification of events over threshold. The FPGA is responsible for initializing and synchronizing all three hodoscope planes such that the timing jitter in control signals between any two SVX chips in the 12 chip array is less than 100 ns (@10 Mhz). The FPGA ensures that all chips are in the same part of the Reset, Integration, or Readout cycle and that the LIVE time window for each hodoscope plane is identical. Due to thermal, board space, and component height restrictions, the FPGA resides on the HC analog board and all control signals will pass through the backplane to get to the hodoscope board.

The SVX requires about 170 mW per chip, utilizing +6V analog and +5V digital power. The three planes of the POEMS Hodoscope will utilize 12 SVX chips for a total power of approximately 2 watts. It is intended that the SVX die will be mounted on the hodoscope board by using flip-chip technology, i.e. mounting the chip upside-down and attaching the die directly to the detector surface via indium bumps. The detector mask has been modified such that the metallization of the detector strips is an exact match to the mirror-image of the SVX bond pads. The indium bump bonding technique is a low temperature (90°C), low inductance/impedance, high reliability method of attaching a bare die. After bump bonding, and testing the bonds for continuity, the array of indium bumps will be back filled with a low viscosity epoxy to mechanically stabilize the bonds. This epoxy fills the micro-fractures in the bumps and prevents outgassing. The yield is nearly 100% for this process.

FPGA Controller Design

The SVX controller is implemented as a complex state machine in a field programmable gate array (FPGA). This logic section is responsible for initializing the SVX array with the proper chip identifications and configuring each chip to the proper readout mode. Event collection is possible once chip initialization is complete. During operation, the FPGA selects from several different SVX modes - Master Reset (MR), Threshold/Calibration (TC), Partial Analog Reset

(PR), Event Integration (EI), and Readout (RO). Each of these modes requires several steps and branching logic. The state machine controller incorporates multiple commandable timers inside the FPGA to allow programmable state durations. Using a 10 MHz clock, these durations can be commanded in discrete intervals of 100ns.

The SVX controller is designed to read in initial setup parameters from a PROM on a power up reset. Once the controller is loaded, it waits to be enabled by an initialization routine. When enabled, the FPGA initializes each chip in the SVX array and then is ready for operation. The SVX controller starts with a MR of the SVX chips. This involves several steps to clear the integration capacitor, coupling capacitor, hold capacitor, threshold capacitor, and D-latch for each channel. After each capacitor is zeroed out, the system is put in a mode to accept a calibration/threshold pulse. Nominally, the threshold will be equivalent to about 1.5 fC. When the calibration threshold has been acquired, a PR is done. At the conclusion of the PR, the system is configured to the event integration mode. If a trigger occurs during event integration, then the chip array is read out via the RO cycle. If no trigger occurs, the system is reset, either via a PR or MR cycle.

In addition to the SVX control functions, the FPGA controls bus arbitration, ADC conversion and Pulse Height Amplitude (PHA) transmission, Priority In/Priority Out control, auto calibration mode, and the "LIVE" and Trigger handlers.

In the designed operational mode, the SVX chips are daisy chained together with the Priority In (PI) and Priority Out (PO) controls. In the POEMS hodoscope, all the PI and PO signals are brought out to the FPGA controller. In the event of a SVX chip malfunction, the HC boards allow this chip to be removed from the logic chain. In this mode, the failure of one chip will not disable the hodoscope.

The FPGAs to be used for flight are PROM based, i.e., they can be reprogrammed while in the circuit board. This is accomplished either by reloading the data from the on-board PROM or by ground command. It is not necessary to remove the chips from the board to accomplish this reprogramming. Thus, no additional enviromental testing will be required if a reprogramming operation is performed. This reprogramming would only be done in flight if a well identified problem occured in the FPGA chip.

Ohmic Side Readout

Resistor Divider Concept

When we began the Phase B study, we began with the concept of interconnecting the 20 ohmic side strips with individual resistors and having a single readout channel from each end of the detector. We had used this successfully on past detectors for heavy particles. Early on however, our simulations showed that the resistors contributed much more noise than was tolerable for a Minimum Ionizing Particle(MIP) such as an electron. We then had to devise an alternative scheme, in which we read out every strip separately. This complicated the design drastically, since it meant a 10-fold increase in the number of readout channels.

Single Strip Readout

In the current design, each ohmic strip will be connected to a charge-sensitive preamplifier with a conversion gain of 0.45V/pC. Each preamplifier will have a feedback capacitance of 2.2pF and an open-loop gain of 2500, giving an effective input capacitance of 5.5nF. The preamplifiers will be implemented as hybrid microelectronic circuits. Each hybrid package will contain ten separate preamplifiers. Thus, six such packages will be required (two for each detector). These packages will be mounted directly on the Hodoscope Boards adjacent to the detectors.

The 60 preamplifier outputs will be sent to the BSE Analog Board, and each will be input to a shaping amplifier. The shaping amplifier will have a shaping time constant of 1μsec. It will produce a unipolar pulse that peaks at 2μsec and returns to within 1% of baseline in 10μsec. The shaping amplifier will have a pulse gain of 110. Thus, the overall conversion gain of the preamplifier and shaping amplifier will be 0.50V/pC. A full-scale input of 20fC will produce a 1V pulse out of the shaping amplifier. As with the preamplifiers, the shaping amplifiers will also be implemented as hybrid microelectronic circuits, with ten shaping amplifiers per package. Six such packages will be required.

The 60 shaping amplifier outputs will each be sent to a low-level discriminator on the BSE Digital Board and to a peak-hold circuit on the BSE Analog Board. The discriminators will be used to determine which strip on each detector received the charge from an event. The peak-holds will be used to hold the peaks of the shaped pulses in order to measure the height of the pulses and thus determine the amount of charge deposited on each detector strip. The peak-holds will be implemented as hybrid microelectronic circuits, with ten peak-holds per package. Six such packages will be required.

The discriminator outputs will be sent to rate counters on the BSE Digital Board in order to determine the event rate. The rate counting scheme is TBD. The peak-hold outputs will be multiplexed to a 12-bit analog-to-digital converter (ADC) on the BSE Digital Board for sequential conversion to digital. For each event, only the channels (detector strips) which receive charge will be converted.

Hybrid Electronics

Because of the large number of readout channels, the small weight allowance for the hodoscope electronics, and the desire to keep all electronics near the detector, it was decided to implement the preamplifiers, shaping amplifiers, and discriminators in hybrid technology rather than discrete components. This allows us to place the preamplifiers directly by the SSD and saves a significant amount of board space. Prototype hybrids were designed and ordered from a commercial vendor. These are expected to arrive at the end of the year.

Command and Telemetry Interface

The HC Digital board consists of a command processor, a telemetry processor, differential drivers for telemetry, differential receivers for commands, Event SRAM, Command SRAM and PROM, interface logic for handshaking with the BSE, a commandable oscillator, test/diagnostic logic, and digital signal buffering.

The command processor will communicate to the Saclay digital electronics via a differential driver/receiver pair. The digital electronics will provide a command envelope, the command clock, and command data at 10 KHz. Commands will be 16 bits in length with 8 bits of address and 8 bits of data. This provides the four Hodoscope Controller boards with up to 256 commands. The Saclay digital electronics will provide the command envelope which the Hodoscope Controller digital board will use to latch and begin execution of the command. The Command processor will store the complete status of the Hodoscope in the command SRAM. The contents of this SRAM can be inserted in the telemetry stream by ground command to verify the status of the instrument. When the instrument is initially powered on, the command processor will initialize all necessary Hodoscope parameters using the contents of the command PROM.

The command processor FPGA will be responsible for arbitrating both the command and event busses.

PHA and rate data from the BSE will pass through the Hodoscope Controller and use the 10 KHz command clock to shift out the data bits. The Saclay digital electronics will control the rate envelope, which will stimulate the BSE to send rate data. The Hodoscope Controller digital board will provide the differential receiver/driver interface from Saclay to the BSE boards.

The telemetry processor will receive data from the SVX controller FPGA on the analog board (hit id, chip id, and analog status), the ADC (pulse height data), and diagnostic data. This data will be received in parallel and inserted into telemetry packets consisting of 12 bit words. The telemetry processor will generate a 1 MHz clock from the on-board oscillator and use it to shift out telemetry data bits. A telemetry envelope will be generated to notify the Saclay digital electronics that data is available. The Saclay digital unit will use the trailing edge of this signal to latch the telemetry word. The serial clock, data, and envelope signals will be transmitted to the Saclay box via differential drivers.

The digital board will require about 175 mW for the differential drivers and receivers, 275 mW for the SRAM and PROM, 125 mW for the FPGAs, and 25 mW for signal buffering. The total power required for the digital board is estimated at 600 mW.

Digital signals passing between Hodoscope Controller boards will be buffered and slew rate limited to reduce ringing and crosstalk. The connector pinouts of the four Hodoscope Controller boards (2 junction side controller, 2 ohmic side controller) will be integrated such that the four boards can be stacked in any order, facilitating the test and troubleshooting of the unit.

System Design and Testing

Early on, once our designs had progressed a certain amount, we made a breadboard pc of the hodoscope controller circuitry. It was not intended as a flight prototype (it was a simplier design and not packaged as a flight unit), but was quicker to implement. It enabled us to test the system concept, the controller operation, and assess noise problems. Further, we were able to study the SVX "live time" by varying the controller acquisition time window and measuring the rate of increase of the system noise.

We discovered fairly quickly that the SVX chip analog output is quite susceptible to digital noise, especially on the digital power supply lines. The reason for this is that the digital power input pad is directly adjacent to the analog output pad, with no separation or shielding in between them. Other problems were discovered between the optical interface link connecting to the data acquisition PC. Excessive current flow between the FIFO's and the optical interface were leading to noise glitches which in turn were affecting the control circuitry. This was remedied by a modification to the optical interface.

We first studied the system noise and behavior with no detector bonded to the SVX inputs. We measured the channel to channel variations in the pedestals with various integration times and levels of injected charge. For a 5 μsec integration time the mean pedestal was seen to be 2.325 Volts with a sigma of 0.0046 Volts = 4.6 mV. The sigma for112 of the 128 channels was less than 0.3%, while for the remaining 16 channels the variations ranged up to $\approx$ 1%. It was seen that these large sigmas were coming from every other channel for channel numbers above 80. This peculiar behavior was traced to the digital section of the PCDAQ.

Using our AC coupled prototype detector, we next allowed the integration time to vary between 500 nsec and 25 μsec in order to find the operation point with the largest system live time. From 1 μsec out to 25 μsec, our measurements showed an almost linear rise in the FWHM of the injected signal from roughly 15 keV up to almost 35 keV. With the signal from 1 MIP being $\approx$ 100 keV, even 15 keV (a $\approx$7:1 S/N ratio) is marginal. However we were fairly confident that an improved board layout with additional filtering and an improved interface could reduce the noise at least another 30%. Some simple improvements yielded a level around 10 keV at 5 μsec. This is about the highest acceptable noise level so we felt comfortable accepting 5 μsec as our baseline integration window time. We calculated this would lead to a system live time of $\approx$ 80%.

Finally we made a series of test with different levels of injected charge at the front end of the SVX chip. The levels ranged from 1 fC up to 20 fC (1 MIP = 4 fC of charge). At a level of 4 fC, the charge resolution was measured to be $\approx$ 5% and at 8 fC $\approx$ 2 %. At the highest charge level a nonlinear behavior was observed in the SVX response. This is not surprising as this chip was not designed for a large dynamic range. However this does show that for the POEMS experiment, the dynamic range is quite suficient.

At the time the project was cancelled, we had placed orders for the hodoscope boards and the hybrid preamplifiers. The hodoscope boards arrived about a month late, not until September, and the manufacturer did not supply all the required test documentation. Thus we were forced to send the boards back for re-testing. The hybrid preamplifiers were supposed to arrive in early December, but have not yet in fact arrived. We have on hand currently enough parts to populate two full hodoscope boards. We will certainly completely assemble and test one board for a proof of principle.

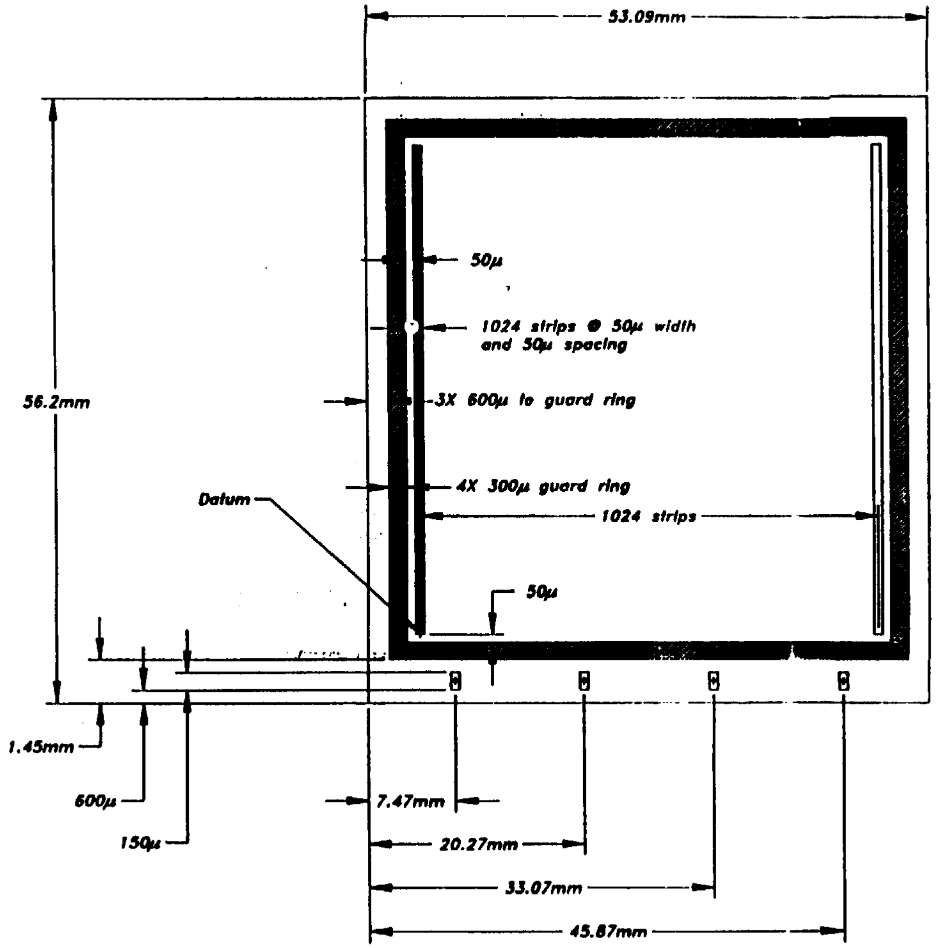
Power Supplies

Goddard also performed a study of the POEMS power supply requirements. We polled the electronics groups for specifications which we built into a requirements table. We also proposed a power distribution scheme for the instrument.

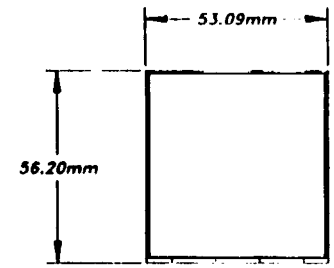
Mechanical Design

The main mechanical structure was the Chicago responsibility for the SMEX POEMS. The hodoscope boards however by their very nature must be in close proximity to, or mounted onto the magnet itself. Further, the SSDs need to be in a purged, light tight enclosure. The mechanical design of the hodoscope board mounting is then intimiately tied to the assembly and mounting of the magnet. The magnet is a split dipole, with each of the halves consisting of 6 segments. Once magnetized, these segments will want to repel each other with a substantial force. Thus the structure to hold the magnet assembly together must be carefully considered. It was also desired to be able to remove one of the hodoscope planes easily if a problem developed.

Goddard took the lead in designing endcaps into which the magnet segments could fit, and into which slots were machined. These slots have rails which allow the hodoscope boards, with matching rails, to slide into position into the magnet bore. The entire assembly is drawn together by four threaded rods that run the entire length of the magnet. A simple box is mounted on one side and into which the hodoscope electronics fits. The entire magnet-hodoscope assembly, when assembled, is a single integrated unit which is ready to be itself integrated onto the spacecraft deck.



SCHEMATIC REPRESENTATION OF DETECTOR FOR DIMENSIONAL PURPOSES



DETECTOR AT ACTUAL SIZE (REF.)

GC1490490

ALL DIMENSIONS IN MILLIMETERS

LIST OF MATERIAL

Goddard Space Flight Center

TOLERANCES: .XX ±.02 .XXX ±.005 ANGLES ±.1° FRACTIONS ±1/32 125/

	NAME	DATE
DESIGNED	SHAFFER	9-13-94
DRAWN	SHAFFER	9-13-94
CHECKED	TREXEL	
APPROVED	BARBIER	

POSITION SENSITIVE STRIP DETECTOR OUTLINE DRAWING– POEMS/SMEX

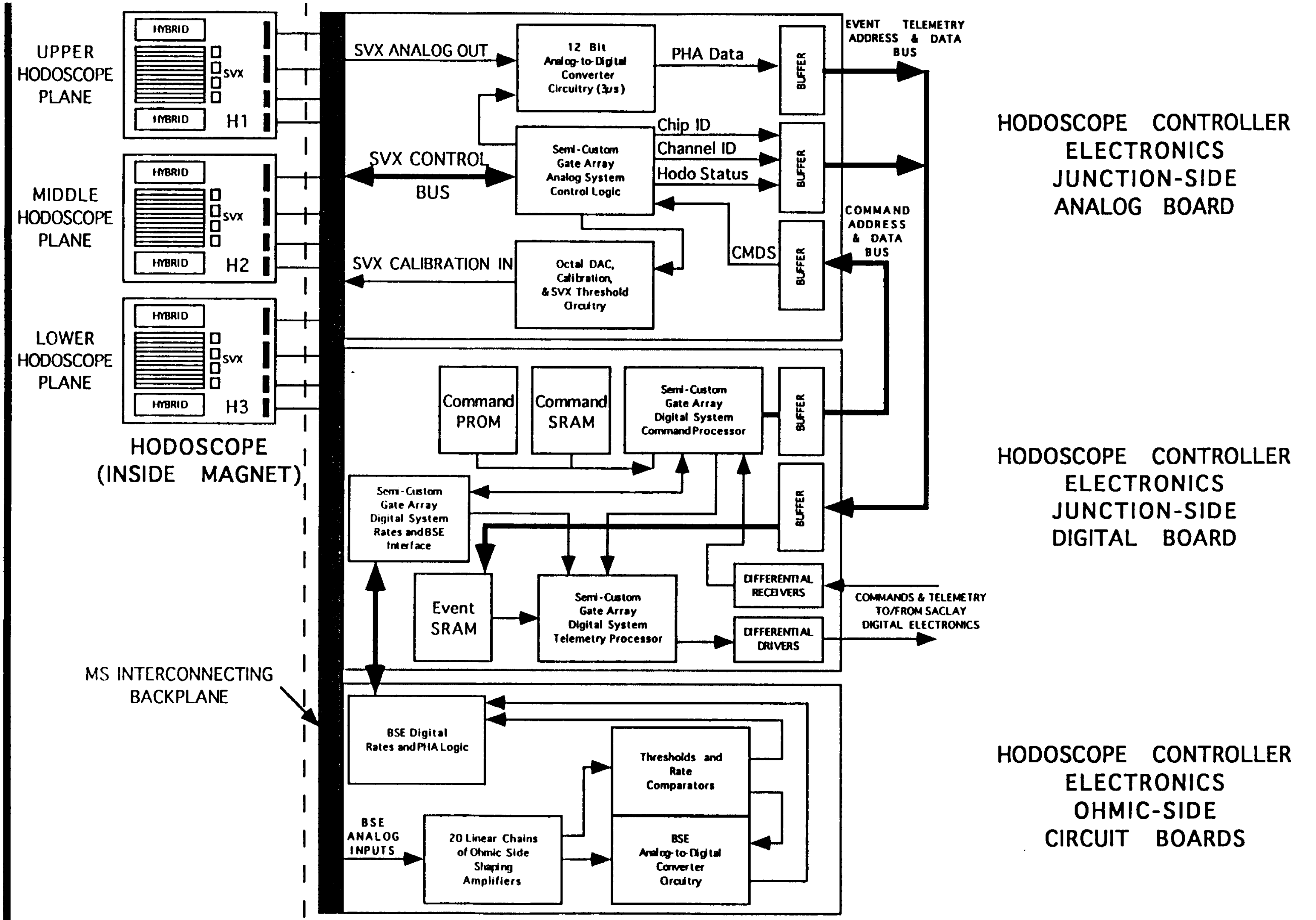
GC1490490

667 1/1 SEPT. 16, 1994

THIS DRAWING WAS PRODUCED USING SOFTWARE AUTOCAD VERSION R12 FILE NAME GC1490490.DWG

NEXT ASS'Y: NONE USED ON: POEMS

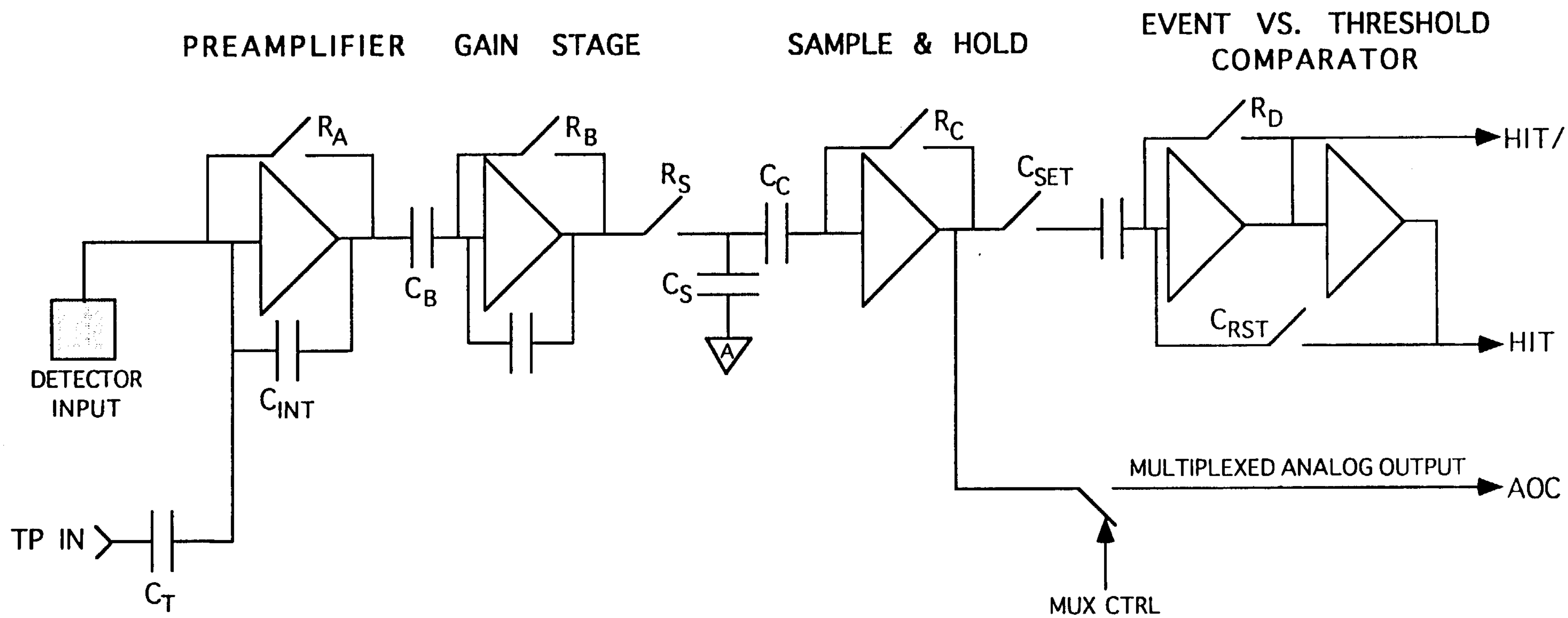
REVISIONS: SYM DESCRIPTION DATE APPROVAL



POEMS MAGNET SPECTROMETER HODOSCOPE ELECTRONICS

7/1/94

SVX ANALOG FRONT END SCHEMATIC
(1 OF 128)



OPEN LOOP GAIN = 2000; FEEDBACK CAPACITOR = 0.3 pF

CHARGE TERMINATOR AT TP INPUT = 0.03 pF

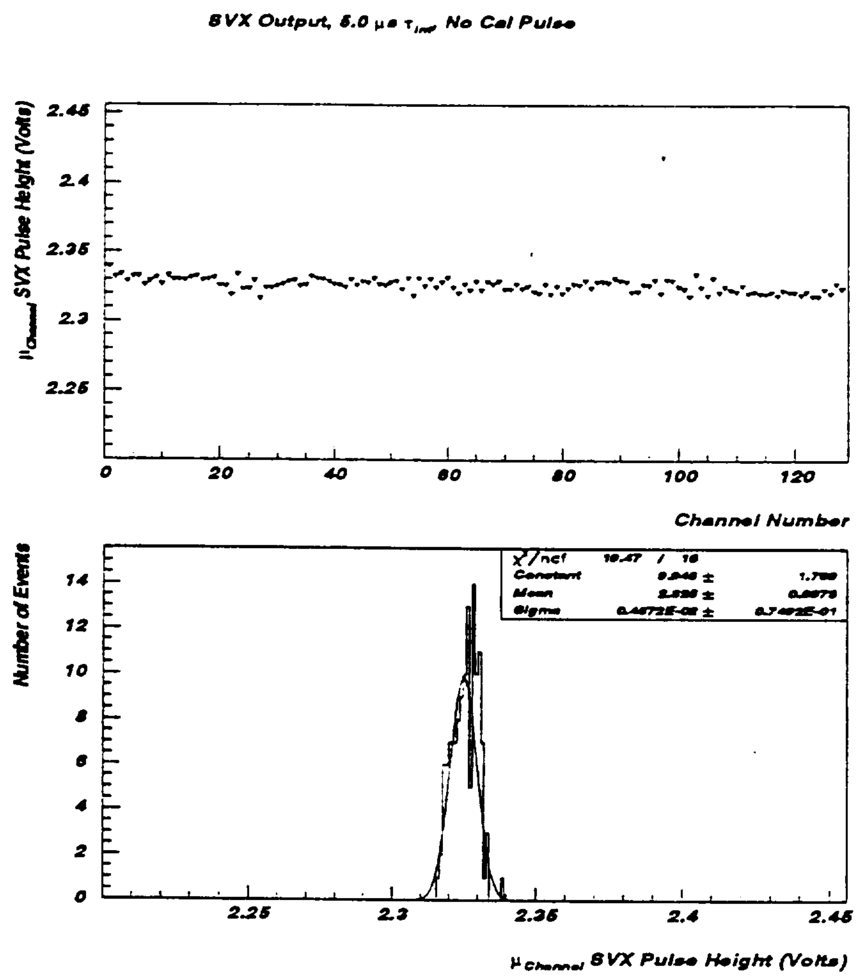
EQUIVALENT INPUT NOISE = 350 ELECTRONS RMS

READOUT SPEED = 1800 nS PER CHANNEL

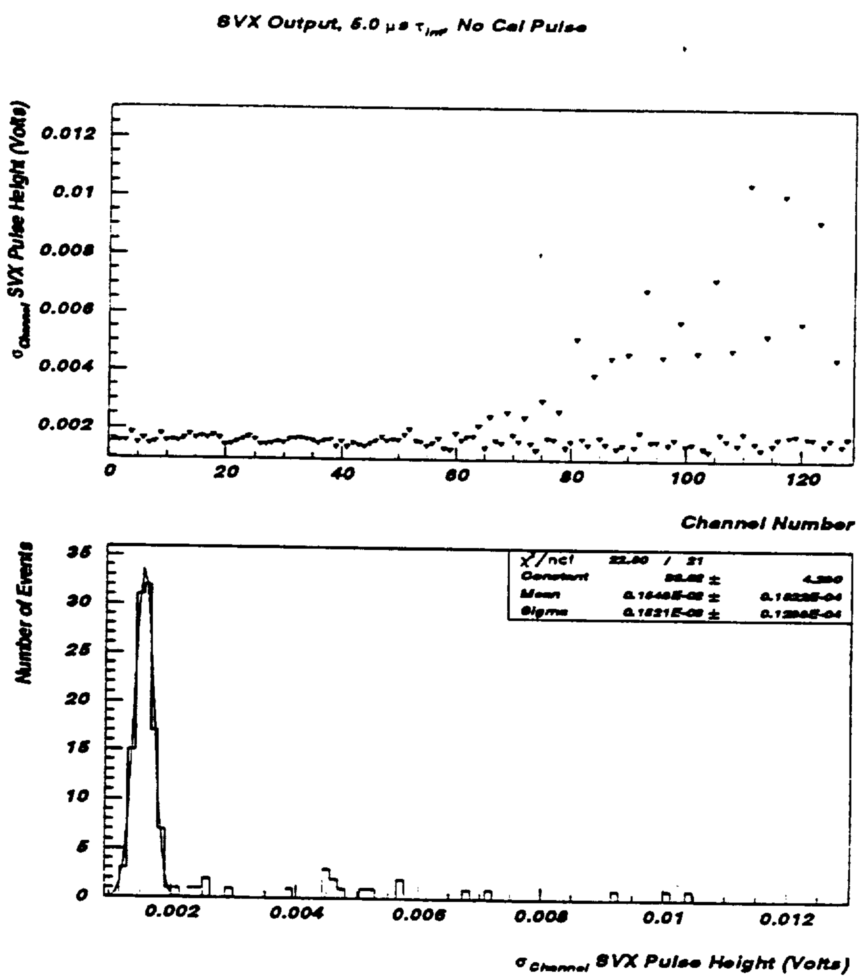
CHARGE GAIN = 15 mV/fC; RANGE = -25 TO 60 fC

7/15/94

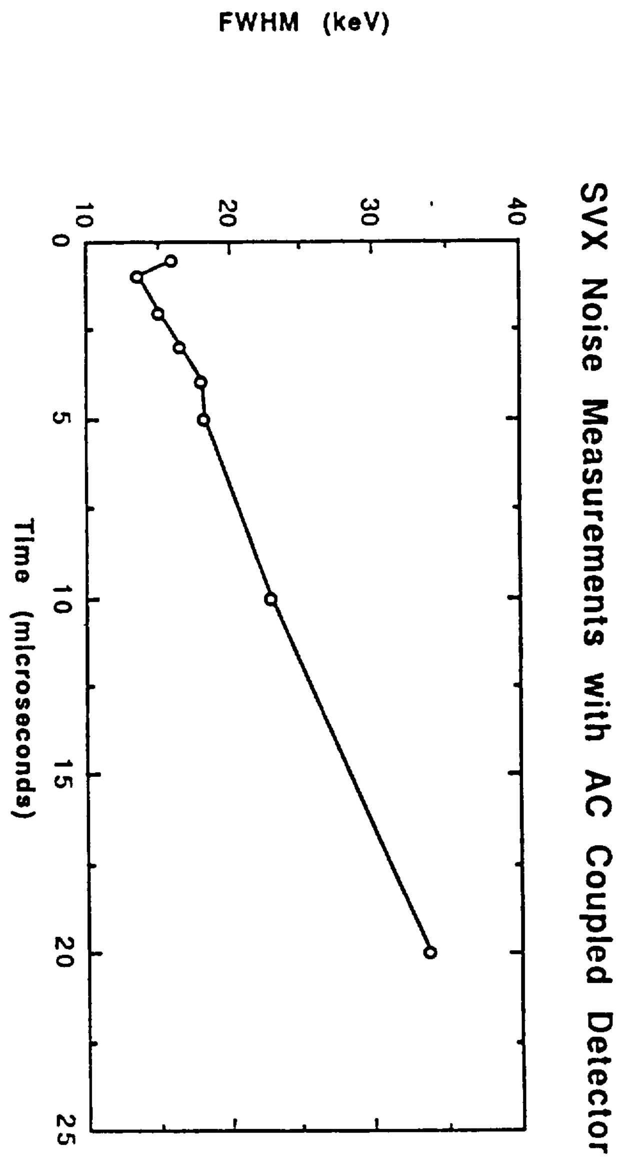
The SVX channel by channel mean ($\mu_{channel}$) for 100 events with no injected charge.



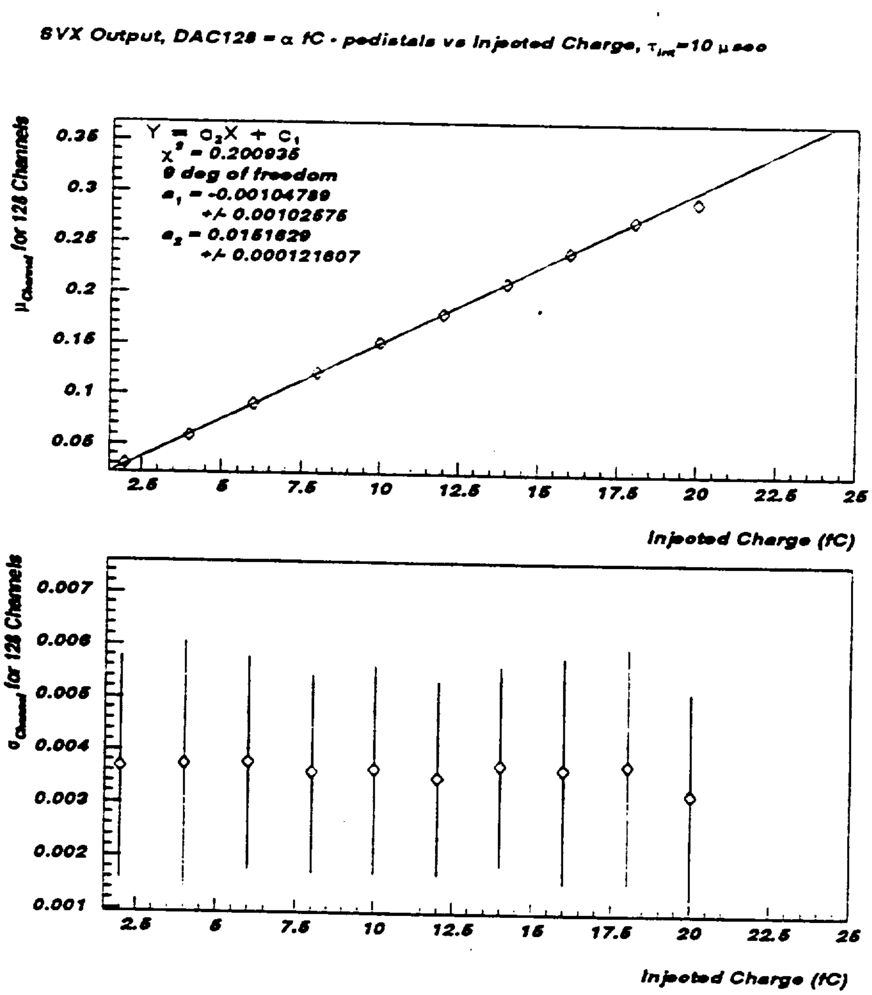
The SVX channel by channel standard deviations for 100 events with no injected charge.



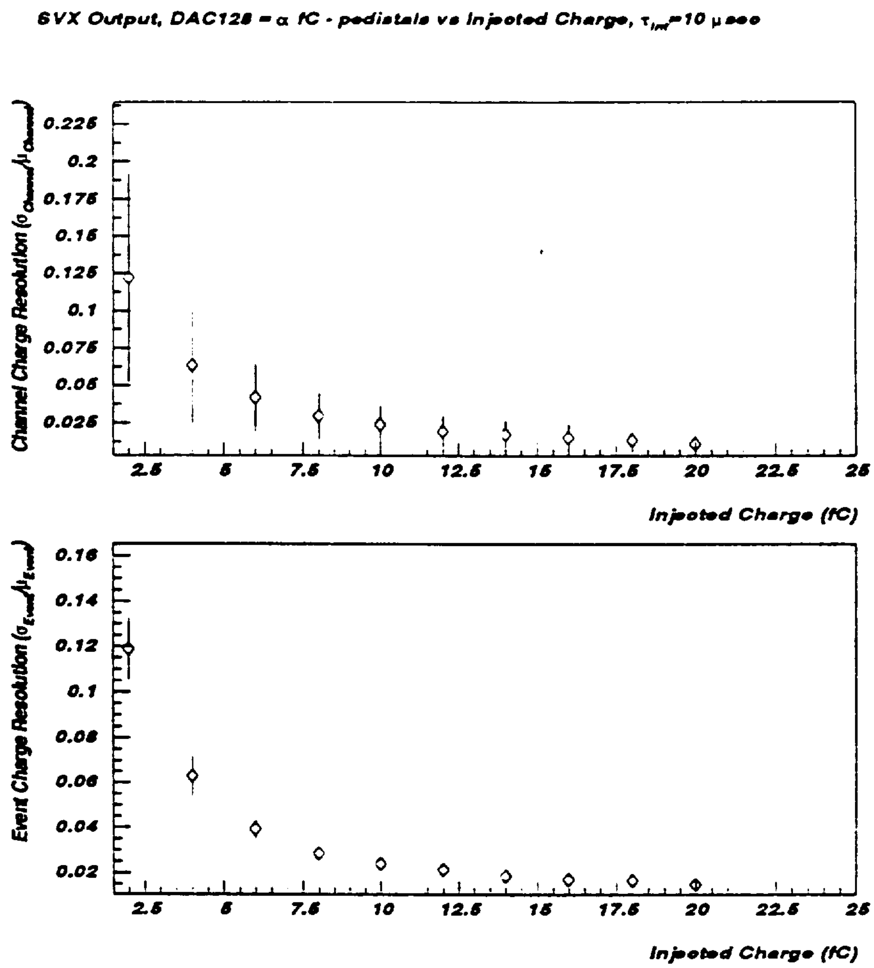
The electronics noise in keV as a function of event integration time using the single sided POEMS prototype detector.



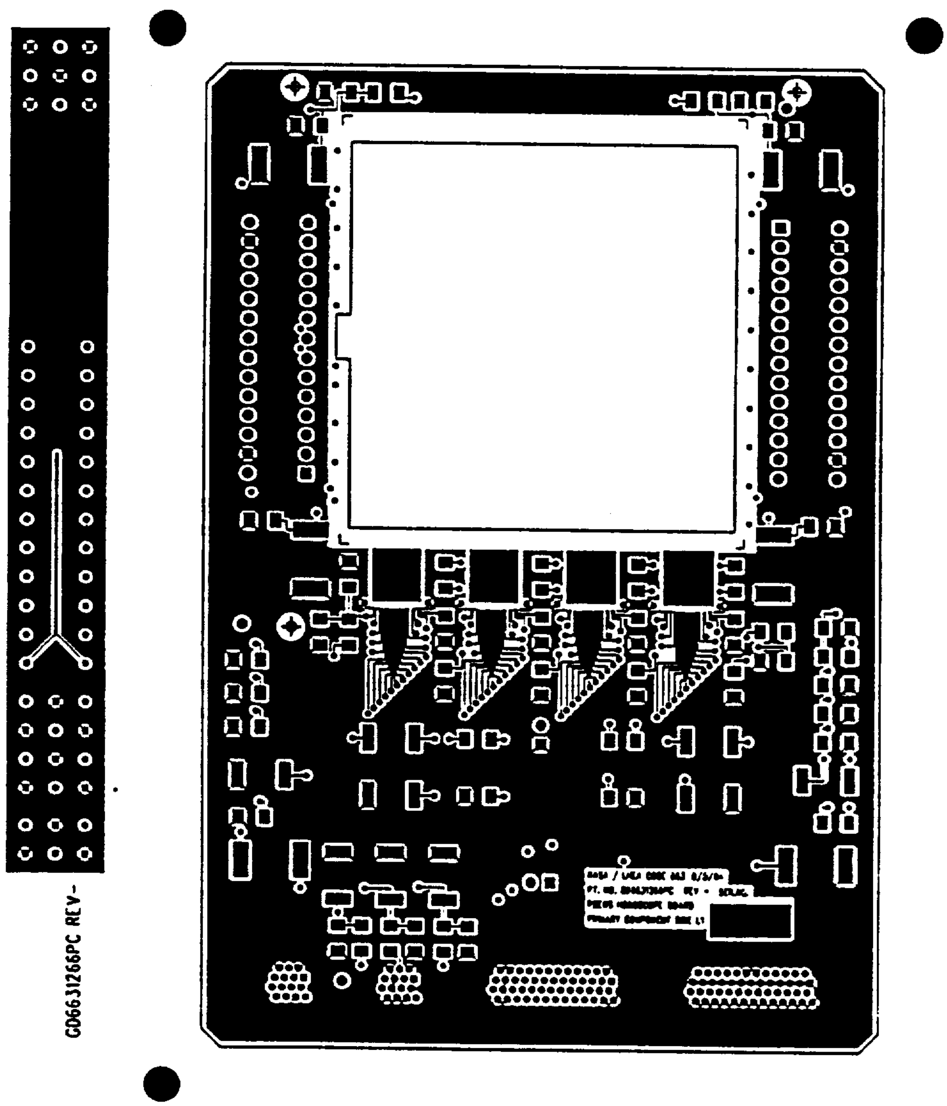
The SVX channel by channel mean and standard deviation as a function of injected charge for a 10 μsec integration time.



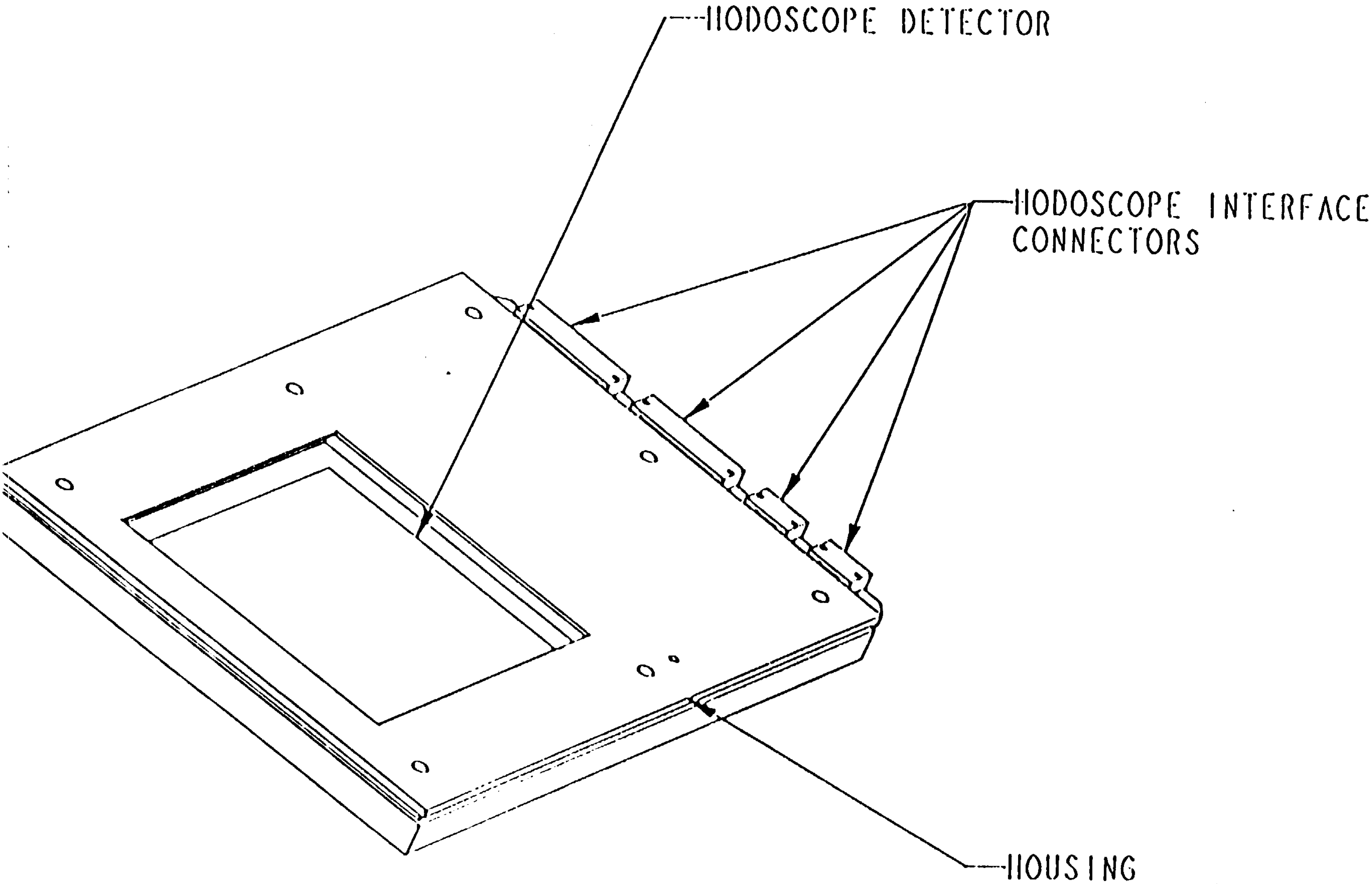
The SVX charge resolution as a function of injected charge for an integration time of 10 μsec.

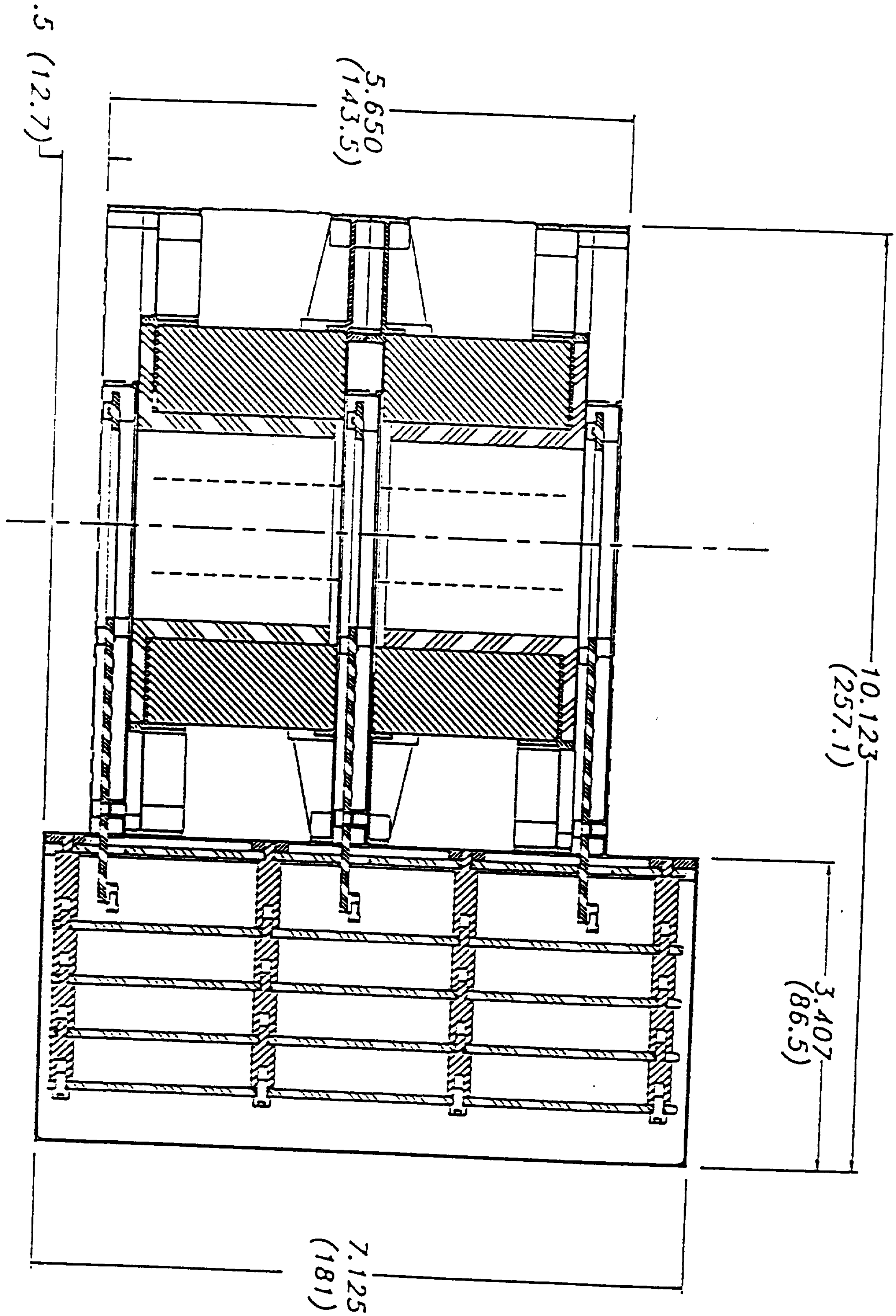


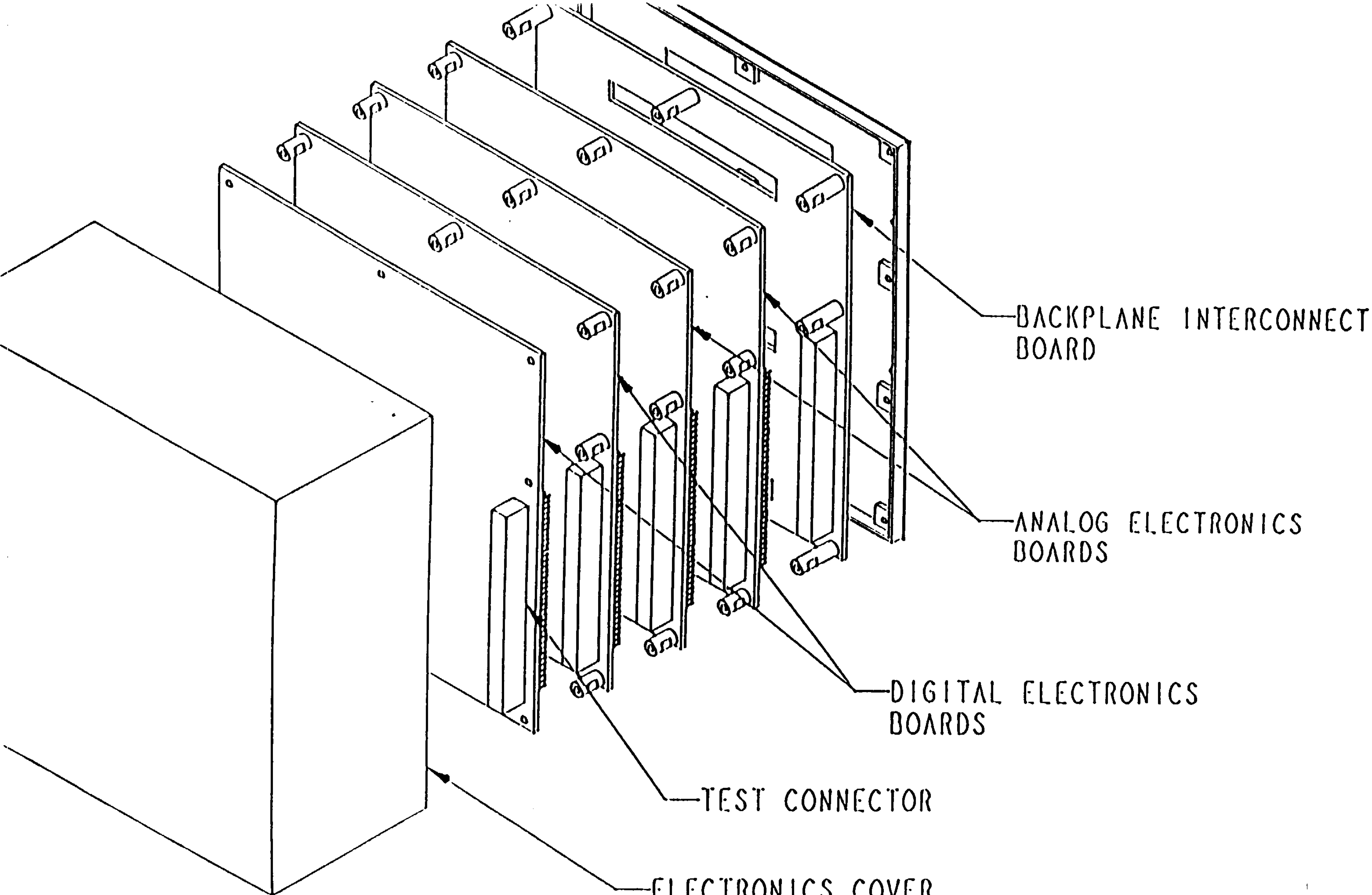
NAME	INIT	DATE	
PCB DESIGNER P.GOODWIN		7/28/94	NASA / GSFC GREENBELT,MARYLAND
CHECKED D.SHEPPARD			POEMS HODOSCOPE DETECTOR BD. PRIMARY COMPONENT SIDE LAYER 1 OF 12
APPROVED D.SHEPPARD			
APPROVED L.BARBIER			REV -, CODE 663, PT.NO. GD6631266 AR
APPROVED			DWG.DATE 8/10/94, NEXT ASSY. GD6631266PC
APPROVED			SOFTWARE REV. PADS2000 6.0, FILENAME HODO8.JOB



GD6631266PC REV-


HODOSCOPE DETECTOR
HODOSCOPE INTERFACE CONNECTORS
HOUSING


.5 (12.7)
5.650 (143.5)
10.123 (257.1)
3.407 (86.5)
7.125 (181)


BACKPLANE INTERCONNECT BOARD
ANALOG ELECTRONICS BOARDS
DIGITAL ELECTRONICS BOARDS
TEST CONNECTOR
ELECTRONICS COVER

Appendix D

Final Report from the University of Arizona

SMEX/POEMS
Phase I Final Report
(Submitted to Bartol Research Institute)

Jokipii attended two meetings of the SMEX team and developed computer modeling and presentation materials to be used by the project.

He attended the meeting held in Greenbelt, Maryland on February 8-11, 1994. At this meeting he contributed to the discussions regarding the strategy of the observational program and to the various theoretical issues which arose during the discussion.

He also attended the team meeting at Kiel, Germany, on June 18-25, 1994, at which he contributed further to the observational strategy and provided other information.

Jokipii developed computer routines which illustrated the various expected electron and positron observational parameters, based on the most recent theoretical models. These were used both to plan observational strategies and to make presentation materials.

Work was initiated on a publication of some of the simulations jointly with Wefel and Guzik of LSU.

University of Arizona
December 1994

Appendix E

Final Presentation to the Associate Administrator for the Office of Space Science at NASA Headquarters.

POsitron Electron Magnet Spectrometer

POEMS

SMEX Follow On Candidate Mission

Presentation to the Associate Administrator

NASA Headquarters

September 1, 1994

Science Overview and Instrumentation

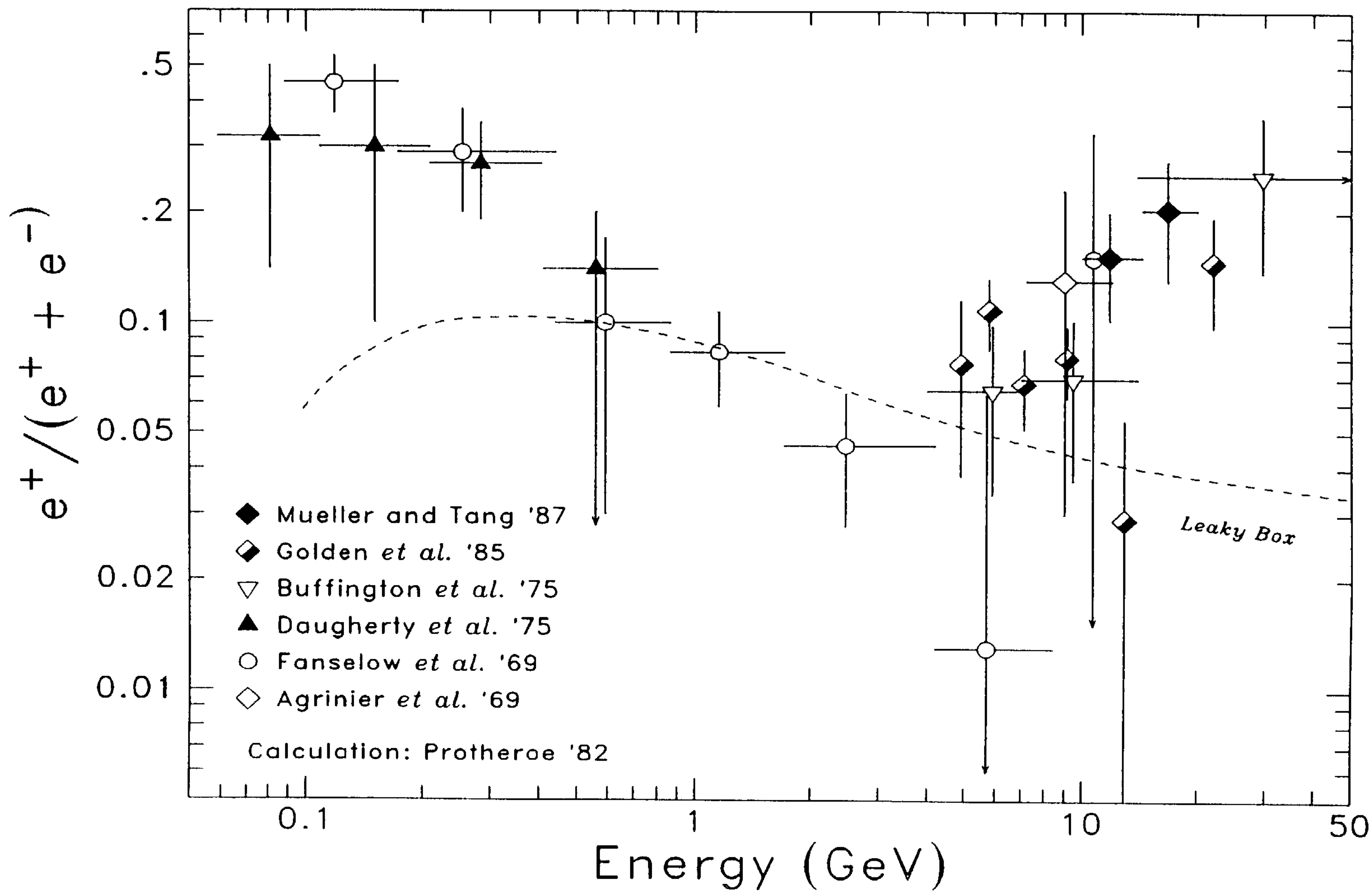
Paul A. Evenson

Bartol Research Institute

Principal Investigator

Summary of Previous Positron Measurements: Large Uncertainty; Disagreement with Theory

POEMS



Electrons and Positrons in Space Plasmas: Essential Scientific Background

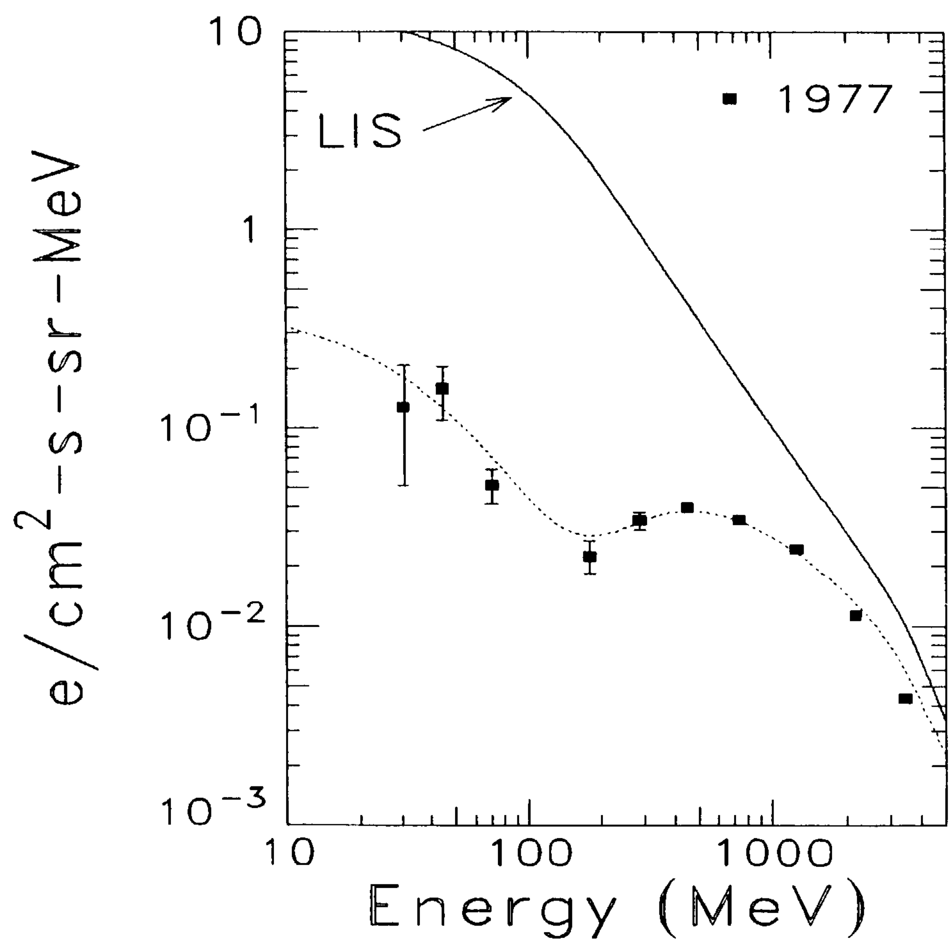
- Observed negative excess demonstrates that electrons exist as a primary component of Solar, Galactic, and Jovian cosmic rays.
- Scientific progress requires good measurements of relative positron abundance at the 10% level. POEMS is not a "needle in a haystack" search.
- Positrons clearly exist as a spallation product, but participation in the basic acceleration processes is also possible.
- Positrons have limited life in cold material but are stable at cosmic ray energies.
- Production of positrons can be mapped by study of the electromagnetic radiation associated with their production.

POEMS Discovery Objective: Primary Cosmic Positrons

POEMS

- The color viewgraph shows the distribution of gamma radiation from radioactive Aluminum-26 in the galaxy. Aluminum-26 is a positron emitter, and is present over an unexpectedly large fraction of the galaxy. Positrons from this element should be accelerated by the cosmic ray acceleration mechanism originally proposed by Fermi.
- Either detection or non-detection of these positrons as accelerated cosmic rays will have a major impact on theories of cosmic ray acceleration.
- Positrons produced in supernova explosions can also be directly accelerated to cosmic ray energies.
- Upturn in the low energy cosmic electron spectrum cannot be understood in terms of the assumed local interstellar spectrum (LIS).

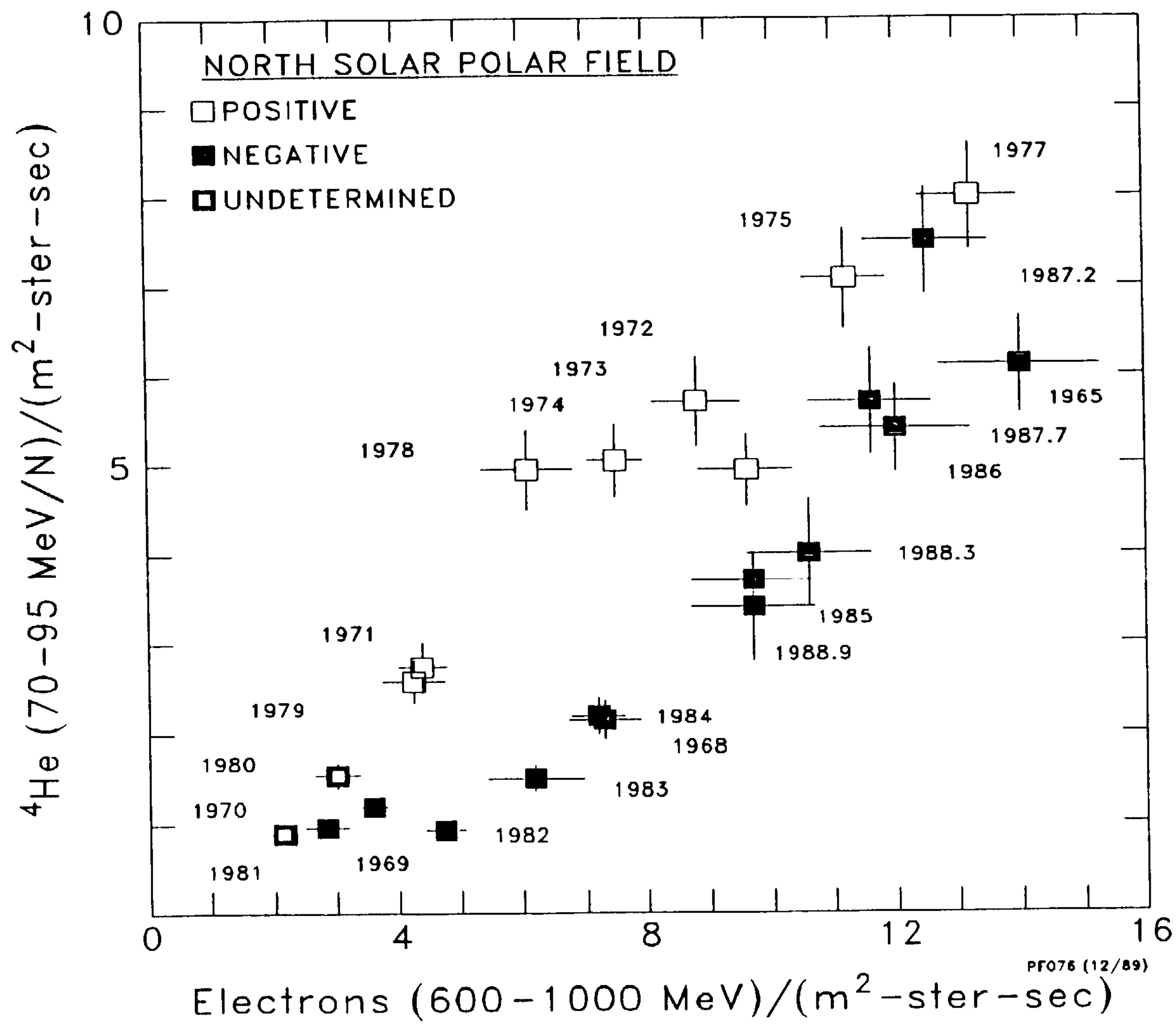
Acceleration of Cosmic Electrons: What Causes the Low Energy Upturn?



POEMS Discovery Objective: Charge Sign Dependent Transport Processes

- The color viewgraph illustrates the counterflowing motion of electrons and positrons due to gradient and curvature drifts in the heliosphere.
- Such systematic patterns are due to lack of reflection symmetry in the Parker field. Non-zero helicity of the turbulence within the solar wind is another example of a non axisymmetric electromagnetic phenomenon of great current interest.
- Particles of opposite charge sign exhibit different behavior in the presence of such magnetic structures.
- Systematic shift in electron/helium ratio when solar magnetic polarity reverses demonstrates that charge sign dependent processes exist.
- Unknown positron fraction makes it impossible to do anything quantitative.

Charge Sign Dependent Solar Modulation:
What is the net charge sign of these electrons?

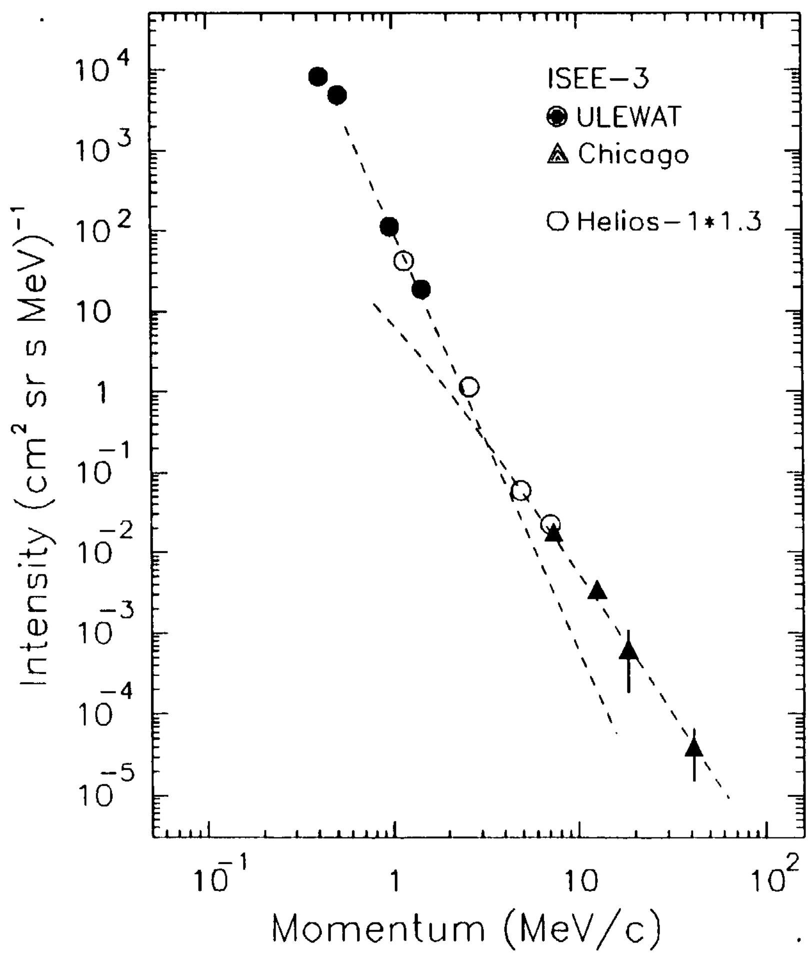


POEMS Discovery Objective:
Solar Flare Positrons

- The color viewgraph is an X-ray image of the sun obtained from the Yokoh spacecraft on July 30, 1994. Magnetic structures in the solar corona, and the connectivity of these structures are a fundamental problem in solar physics.
- Positrons are generated in impulsive, low lying flares, in quantities calculable from the pion decay gamma rays observed from these flares.
- Electron spectra from such flares show evidence for a high energy component comparable in number and spectrum to the positrons produced in this process.
- Whether the positrons escape from the sun is important:
  - If they escape, it demonstrates that the interplanetary and coronal fields are connected in a fundamental but unknown way.
  - If they do not escape, there is a process capable of accelerating electrons to energies of more than 40 MeV on open field lines.

Electron Spectrum from a Solar Gamma Ray Flare: Are there positrons in the second component?

7 June 1980 3:12 UT Flare



POEMS Observation Strategy

- The color viewgraph shows the Earth's magnetosphere, which shields most of the surface from low energy cosmic rays. By placing a spacecraft in a high inclination orbit sufficient observing time may be obtained in regions of low geomagnetic cutoff.
- Observations by POEMS of low energy protons and electrons are required to characterize the time dependent state of the magnetosphere for this analysis.
- Unique and interesting measurements will be made by POEMS of magnetospheric phenomena at a constant local time.
- POEMS will provide the most complete characterization of magnetospheric electrons and positrons to date.

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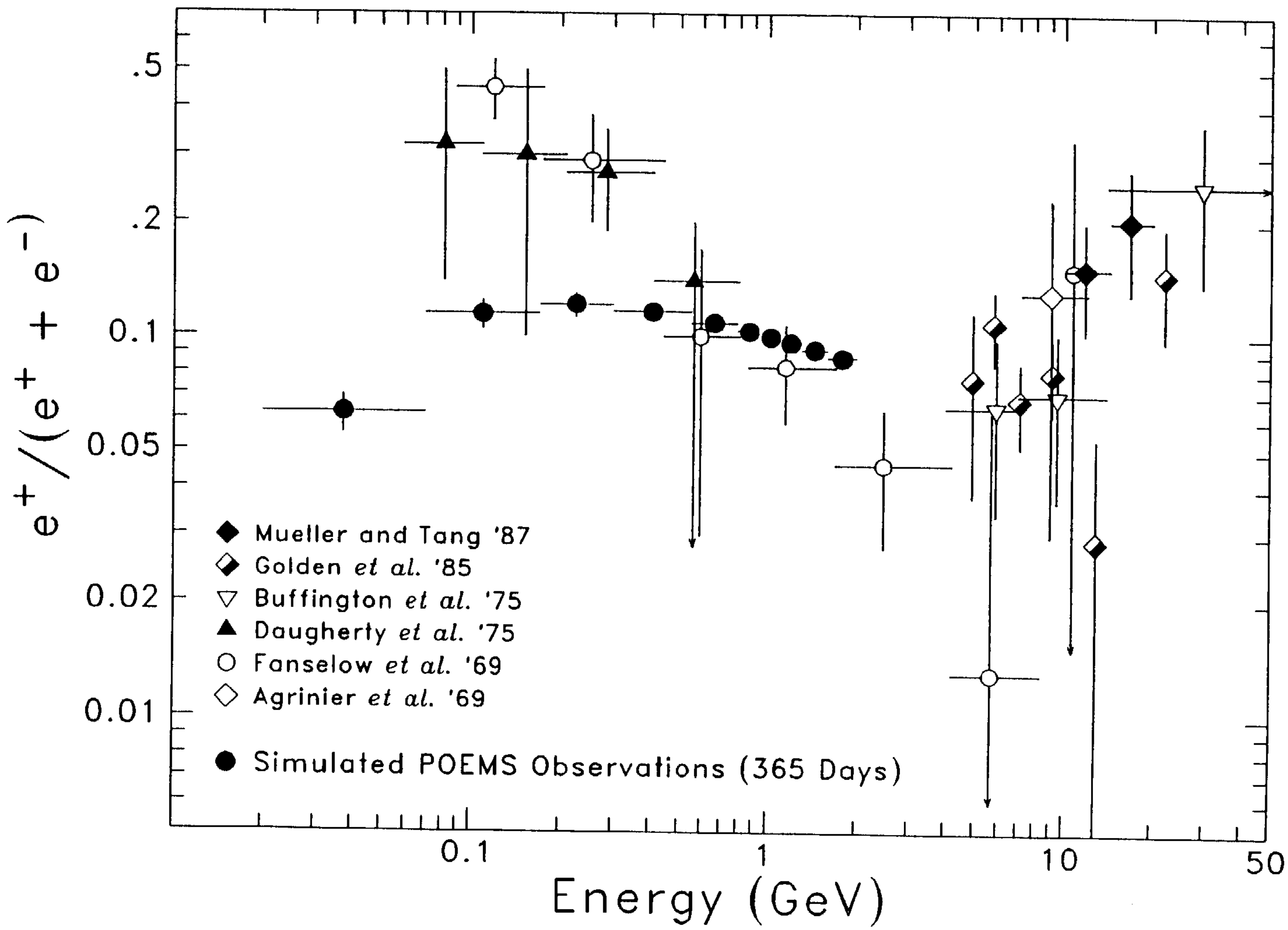
Simulated POEMS Observations
(One Year Mission)



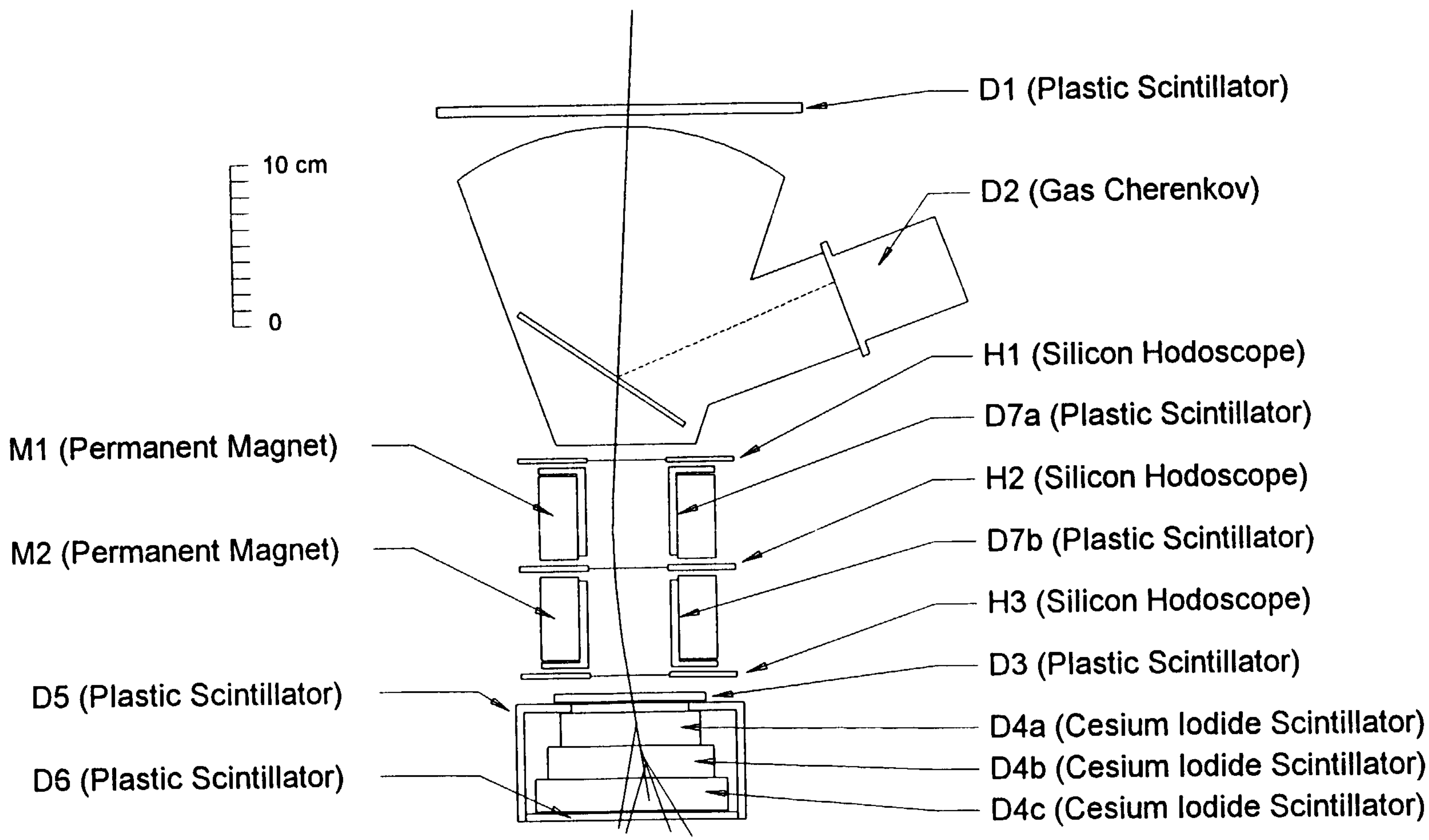
POEMS Mission Summary

- Mission Requirements
  - Polar orbit
  - Zenith pointing
  - One year mission
  - 3.2 Megabytes per day
- Related Observations
  - POEMS explores low energies inaccessible to balloon instrumentation
  - AESOP (Anti Electron Sub Orbital Payload) covers time dependence at intermediate energies
  - HEAT (High Energy Antimatter Telescope) covers high energies where time changes are not expected to be large
- Instrumentation Required
  - Magnet Spectrometer (MS)
  - Energy Extension Sensor (EES)

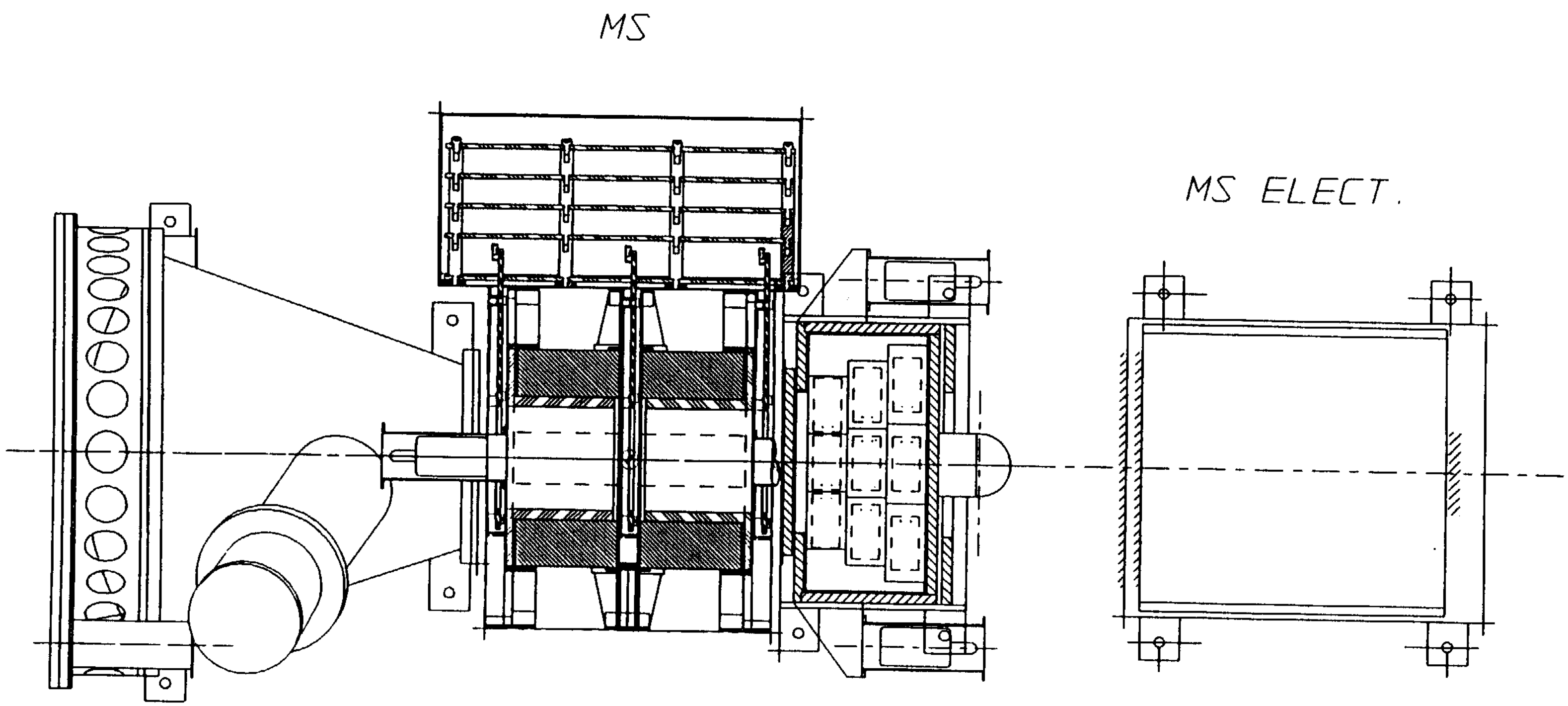
POEMS Payload Component: Magnet Spectrometer (MS)

- Measures positron fraction to an accuracy of one percentage point for a minority composition of 10% from 20 MeV to 2 GeV
- Isolates electrons and positrons over the energy range 20 MeV to 10 GeV from cosmic ray protons using gas Cherenkov detector and Cesium Iodide calorimeter
  - Heritage from OGO-V, ISEE-3/ICE, Ulysses , SOHO
- Separates electrons from positrons using permanent magnet and silicon hodoscope system
  - Heritage from WIND and particle accelerator instrumentation
- Geometry factor becomes energy dependent near low end of energy range, and no response at all below 10 MeV

Magnet Spectrometer (MS)
Schematic Cross Section



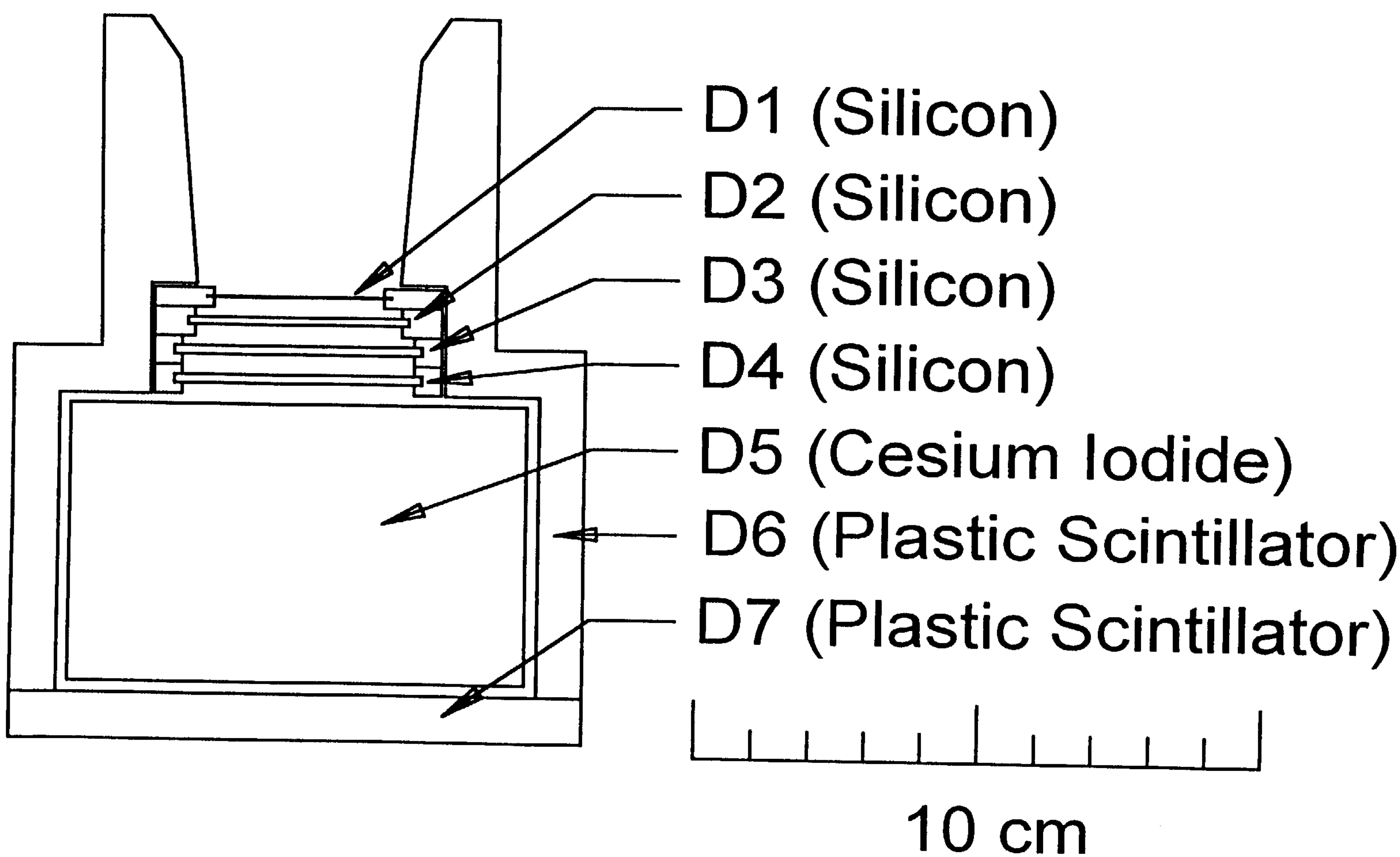
Magnet Spectrometer (MS) Construction Detail



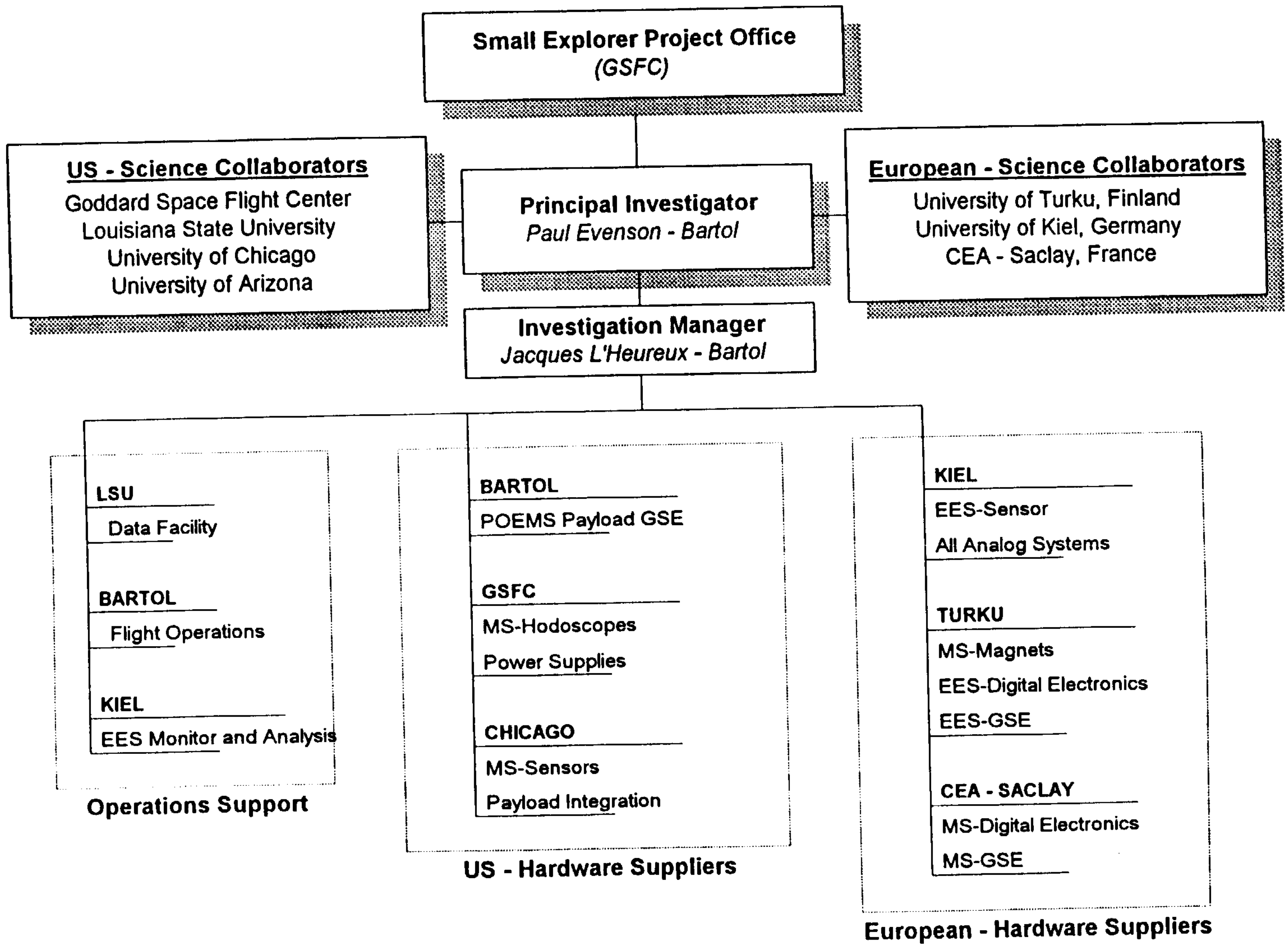
POEMS Payload Component: Energy Extension Sensor (EES)

- Measures total electron spectrum from 150 keV to 50 MeV
- Allows correction for energy dependent MS geometry factor
- Provides characterization of magnetosphere
- Proven design based on modification of the EPHIN system for SOHO

Energy Extension Sensor (EES)
Schematic Cross Section



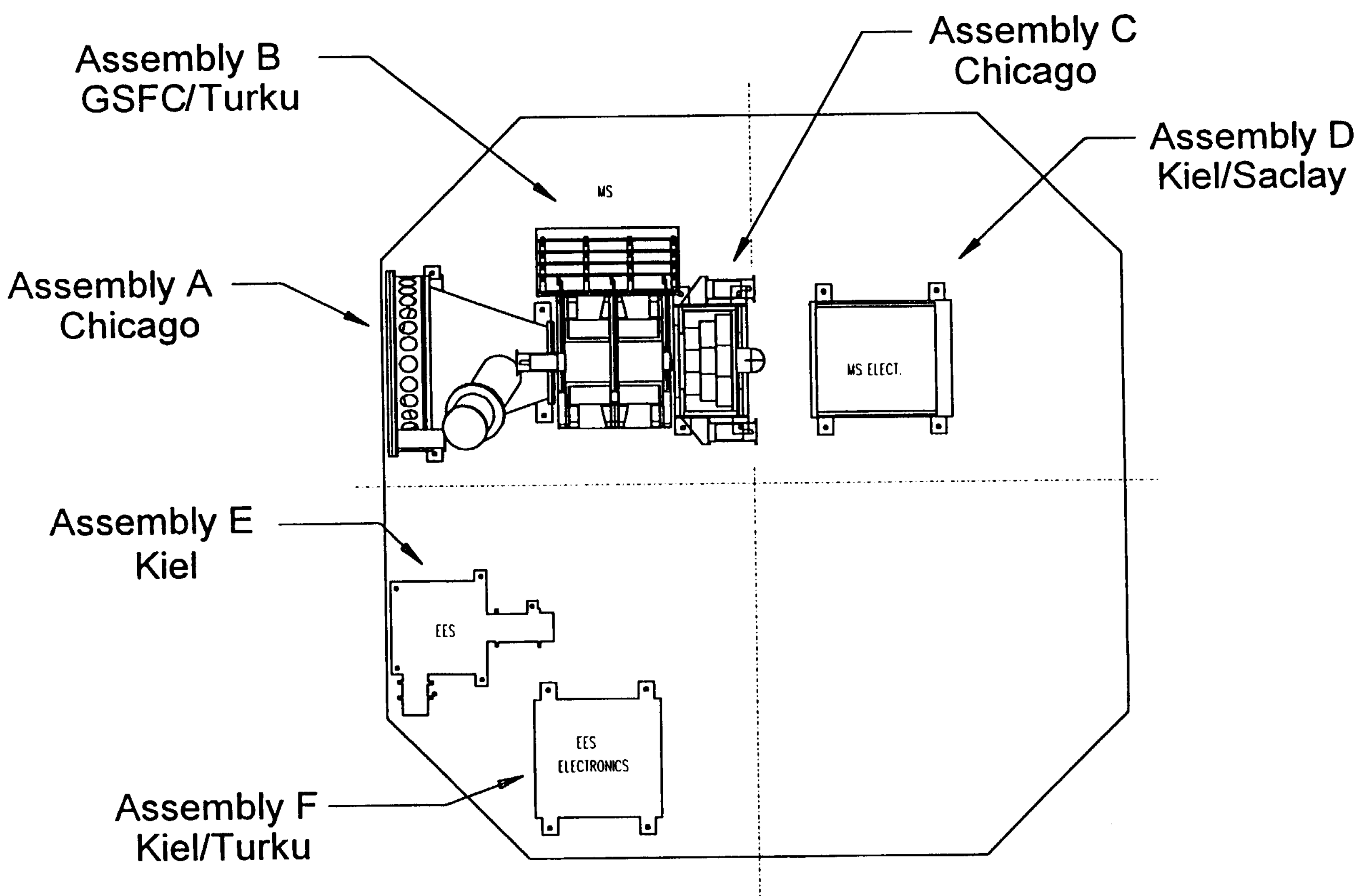
Organization Summary



European Participation in POEMS: Comparison of months of effort

Co-Investigator	Design (11m)	Fabrication (13 m)	Intg./Launch (13 m)	TOTAL (37 m)
US Collaborators				
Bartol Research Institute	29.07	34.23	34.20	97.50
Goddard Space Flight Center	109.03	154.57	94.80	358.40
Louisiana State University	14.57	35.03	47.00	96.60
University of Arizona	0.00	0.00	5.00	5.00
University of Chicago	39.50	54.50	48.00	142.00
Total US Collaborators	***192.17***	***278.33***	***229.00***	***699.50***
European Collaborators				
University of Turku	64.00	6.00	35.00	105.00
University of Kiel	96.00	140.00	99.00	335.00
CEA Saclay	85.00	75.00	43.00	203.00
Total European Collaborators	***245.00***	***221.00***	***177.00***	***643.00***
TOTAL for Project	**437.17**	**499.33**	**406.00**	**1,342.50**

European Participation in POEMS: Source of Payload Components



POEMS Evaluation in Europe

- FRANCE
  - POEMS presented to scientific evaluation body of CNES
  - POEMS science given high rating
  - CNES and CEA evaluations recommend funding if selected by NASA
- FINLAND
  - All Finnish space groups were evaluated by an international committee appointed by the Academy of Finland
  - Preliminary result: High rating for University of Turku Space Research Laboratory (final results due in September, 1994)
  - POEMS presented to top representative of Academy of Finland
  - Final decision depends on international evaluation , but probable funding split between Academy of Finland and TEKES
- GERMANY
  - Special POEMS proposal presented to DARA in February of 1994
  - POEMS presented to Scientific Evaluation Committee of DARA in March. 1994
  - POEMS received "very high" rating by Scientific Evaluation Committee

POsitron Electron Magnet Spectrometer
Definition Phase Summary

POEMS

Characteristic	Proposed	Achieved
MS Geometry Factor	5.0 cm^2-ster	2.5 cm^2-ster
MS Duty Cycle	40%	80%
EES Geometry Factor	0.8 - 5.0 cm^2-ster	5.0 cm^2-ster
Electron Coverage	300 keV - 10 GeV	150 keV - 10 GeV
Positron Coverage	20 MeV - 2 GeV	1 MeV - 3 MeV 20 MeV - 2 GeV
Payload Mass	48 kg	28 kg
Science Power	32 Watts	24 Watts (max. 30)
US Payload Cost	$6,777K*	$6,636K*
Launch vehicle	Standard Pegasus	Standard Pegasus
Exceptions to AO	None	None

* Adjusted to common accounting basis and FY92 dollars

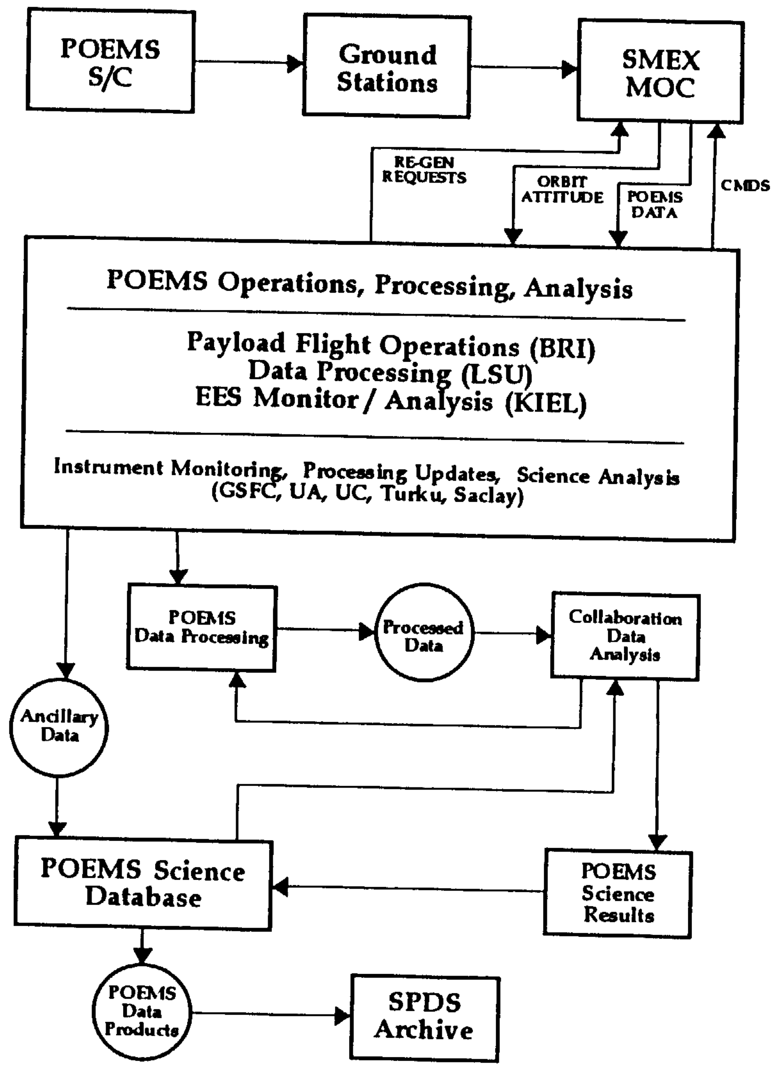
Supplementary Material

POsitron Electron Magnet Spectrometer (POEMS)
Science Objectives

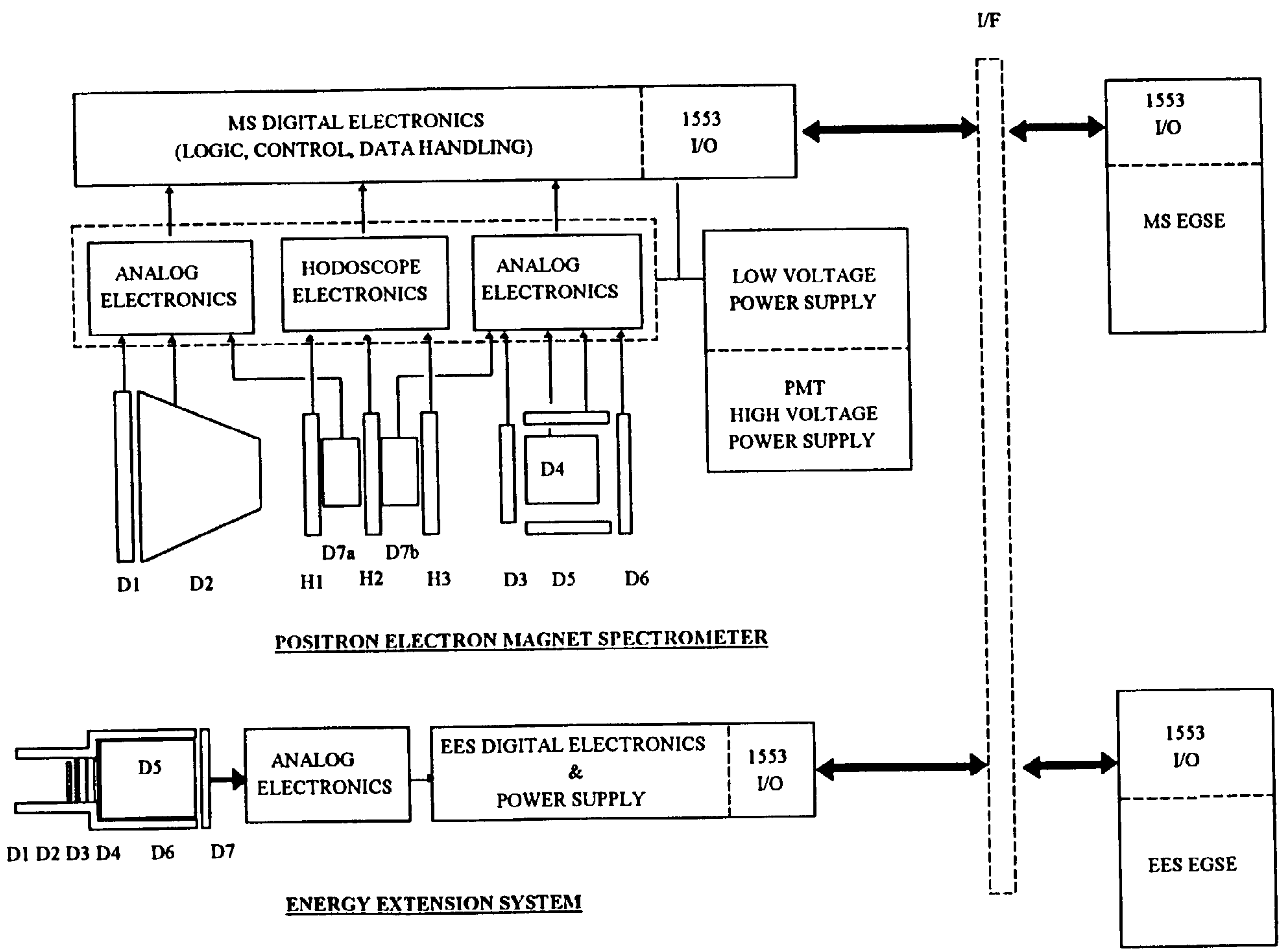
- Determine the degree to which primary sources of positrons contribute to the Galactic Cosmic Radiation
- Measure the charge sign dependence of heliospheric modulation using particles of the same mass and velocity (e+ and e-).
- Investigate the positron fraction of solar energetic particles emitted from different types of flares.
- Utilize secondary positrons to trace the history of the Galactic Cosmic Radiation .
- Relate neutron and gamma ray production in solar flares to electron and positron production.
- Refine understanding of energy spectra of solar and galactic cosmic rays.

Data Processing Flow Diagram

POEMS



Instrument System Diagram

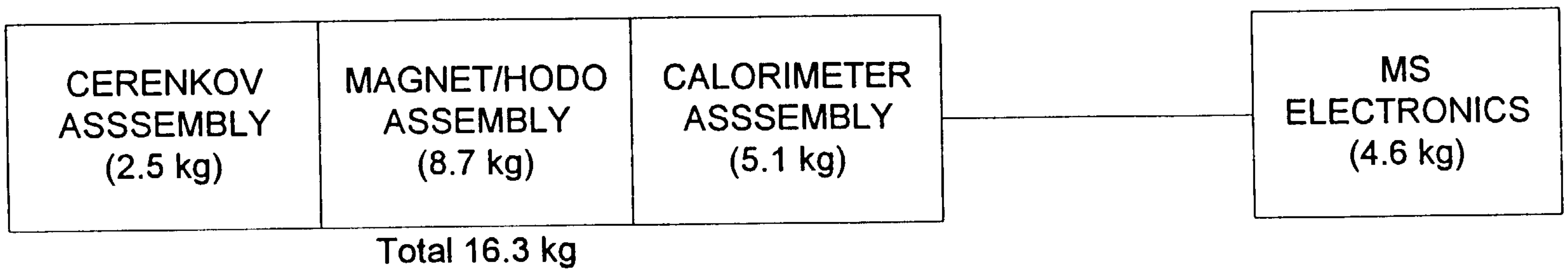


Instrumentation Readiness

- Spacecraft instruments with direct detector heritage
  - Successful Phase B and CDCR for EOS (Current US Co-I's)
  - ISEE-3/ICE (Chicago)
  - SOHO CEPAC (Kiel and Turku)
  - WIND EPACT (GSFC)
  - OGO-V (Chicago and Saclay)
- Other spacecraft with instrumentation produced by collaborators
  - Cospin/Ulysses (Chicago, Kiel and Saclay)
  - CRRES (Chicago)
  - SIGMA (Saclay)
  - VEGA (Saclay)
- While the POEMS payload, and particularly the MS, are new designs they consist entirely of elements proven at accelerators and in previous spacecraft. We therefore do not consider any of the elements of POEMS to be either technology developments or drivers.

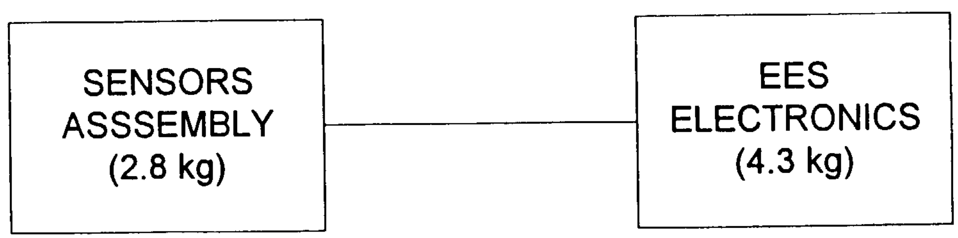
Mass Budget for SMEX/POEMS

Magnet Spectrometer



Total for MS = 20.9 kg

Energy Extension Sensor



Total for EES = 7.1 kg

Total for SMEX/POEMS = 28.0 kg

Power Budget for SMEX/POEMS

POEMS

Magnet Spectrometer

CERENKOV ASSSEMBLY (0.2 Watt)

MAGNET/HODO ASSEMBLY (4.9 Watts)

CALORIMETER ASSSEMBLY (0.2 Watt)

Total = 5.3 Watts

MS ELECTRONICS (10.4 Watts)

Total for MS = 15.7 Watts

Energy Extension Sensor

SENSORS ASSSEMBLY (0.1 Watt)

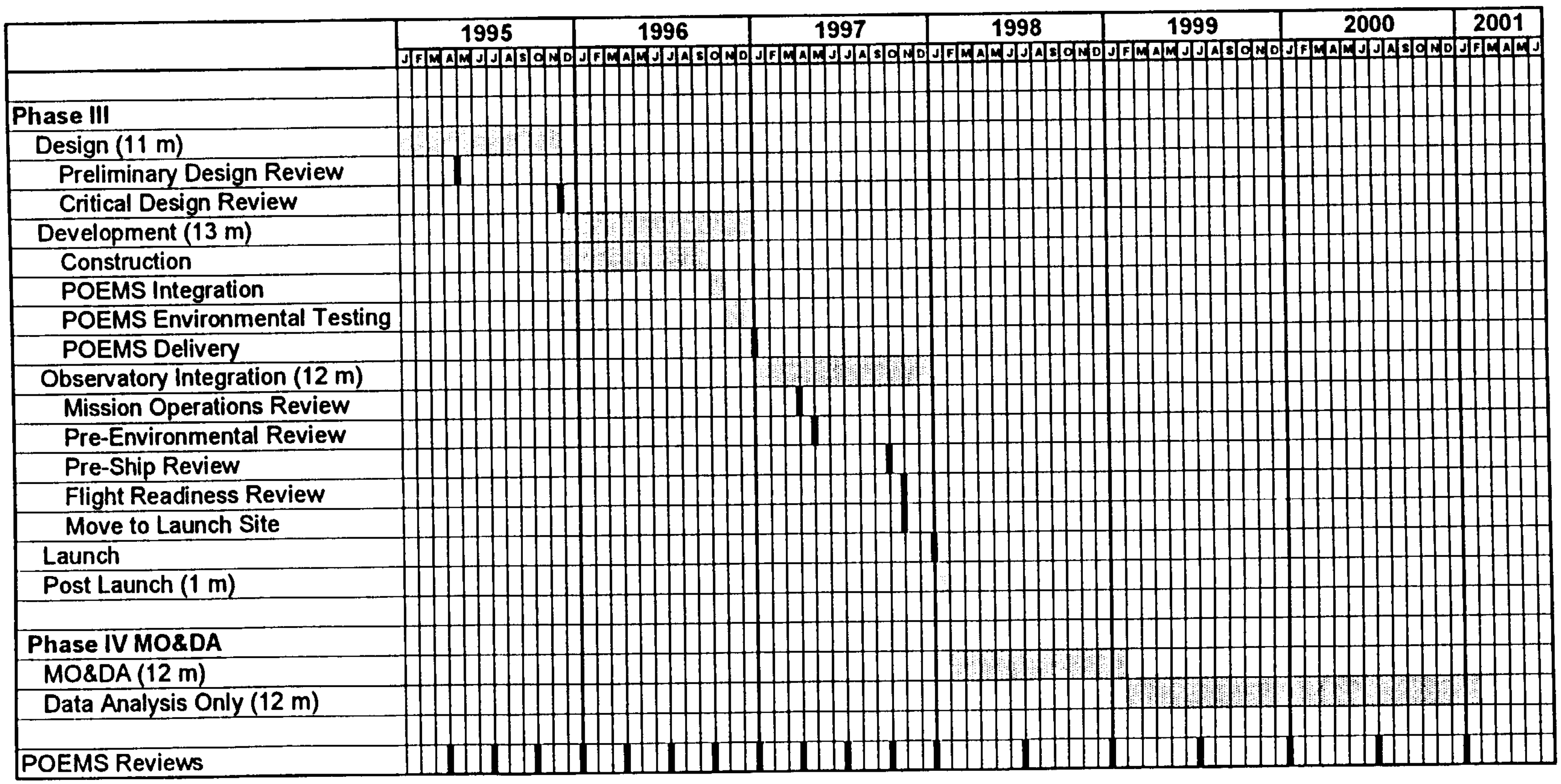
EES ELECTRONICS (7.8 Watts)

Total for EES = 7.9 Watts

Total for SMEX/POEMS = 23.6 Watts

Implementation Schedule Overview

POEMS



SMEX/POEMS Proposed Cost Summary
January 1995 Start; FY92 Dollars

POEMS

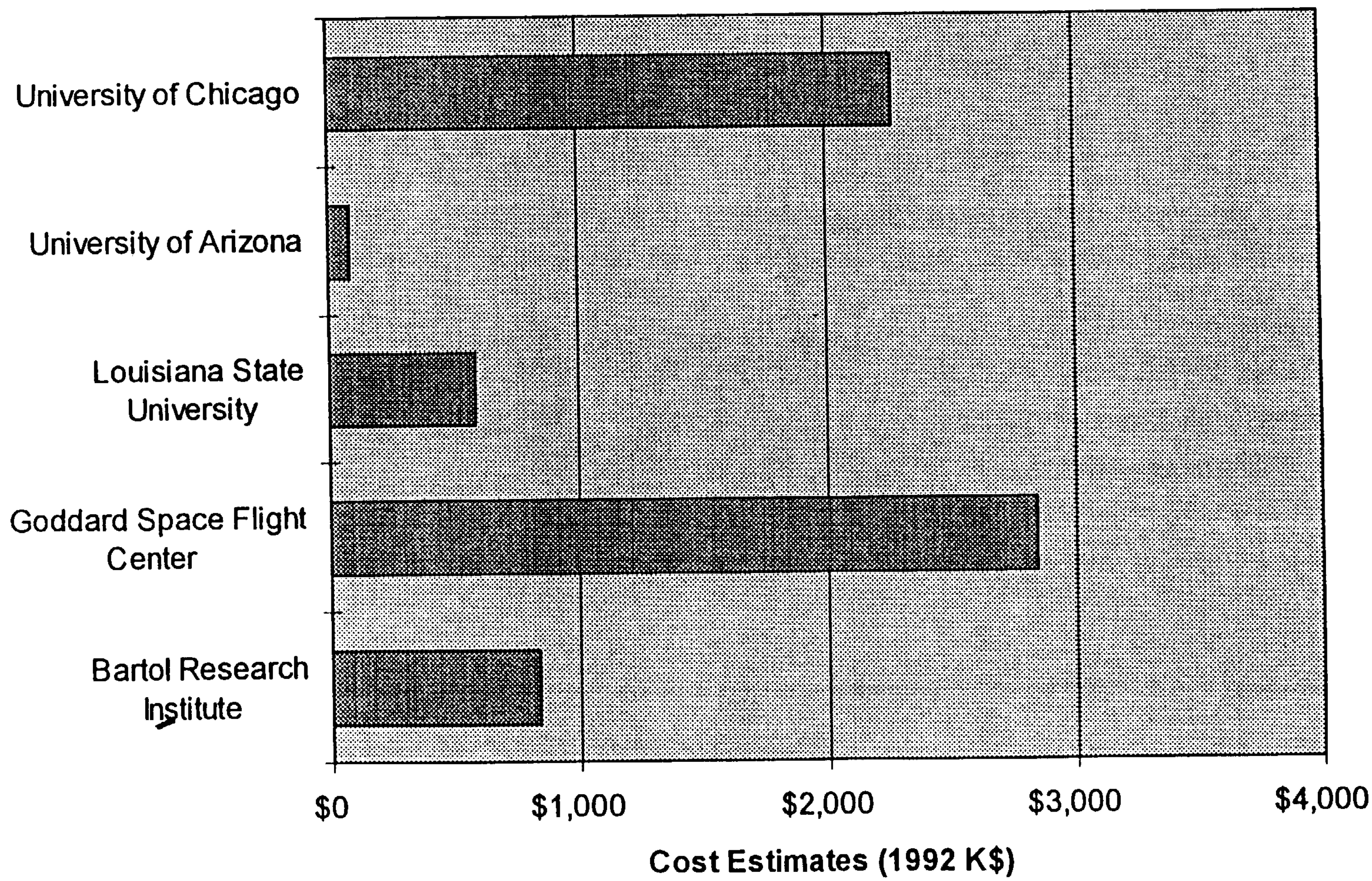
Phase III

Institution	1995	1996	1997	1998	PHASE III
Bartol Research Institute	$222,709	$255,525	$325,738	$32,615	**$836,586**
Goddard Space Flight Center (LHEA)	$1,430,652	$870,261	$451,112	$92,328	**$2,844,354**
Louisiana State University	$188,848	$158,007	$219,084	$25,686	**$591,626**
University of Arizona	$11,402	$11,552	$59,284	$2,040	**$84,278**
University of Chicago	$892,326	$940,319	$437,820	$8,617	**$2,279,082**
TOTAL for SMEX/POEMS	**$2,745,938**	**$2,235,664**	**$1,493,038**	**$161,286**	**$6,635,925**

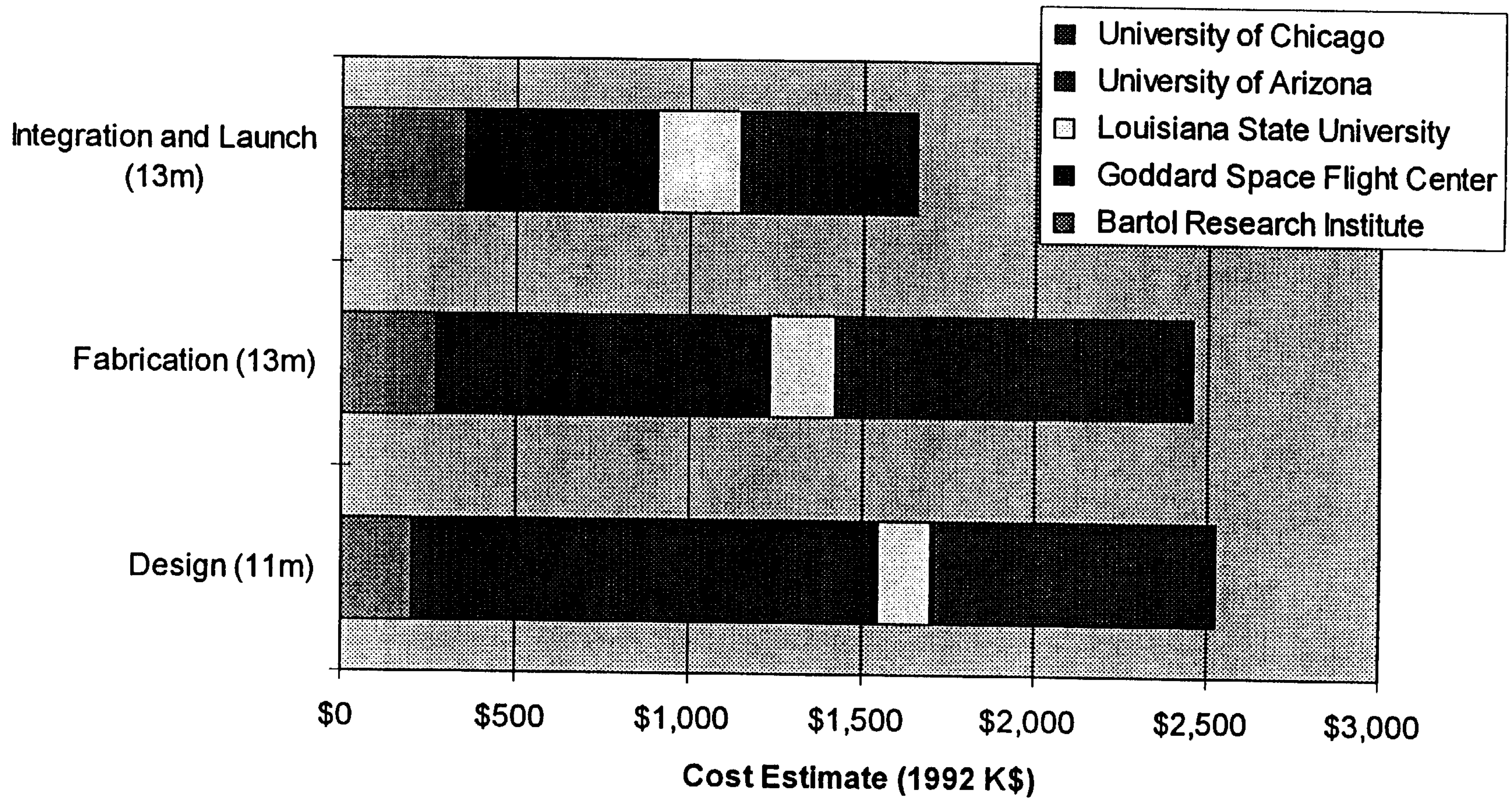
Phase IV

Institution	1998	1999	2000	2001	PHASE IV
Bartol Research Institute	$182,801	$208,115	$204,966	$18,730	**$614,612**
Goddard Space Flight Center (LHEA)	$329,915	$253,361	$215,388	$0	**$798,665**
Louisiana State University	$187,575	$195,371	$194,006	$13,555	**$590,507**
University of Arizona	$88,325	$94,480	$94,202	$3,711	**$280,719**
University of Chicago	$191,263	$159,378	$155,740	$11,506	**$517,888**
TOTAL for SMEX/POEMS	**$979,880**	**$910,706**	**$864,303**	**$47,503**	**$2,802,391**

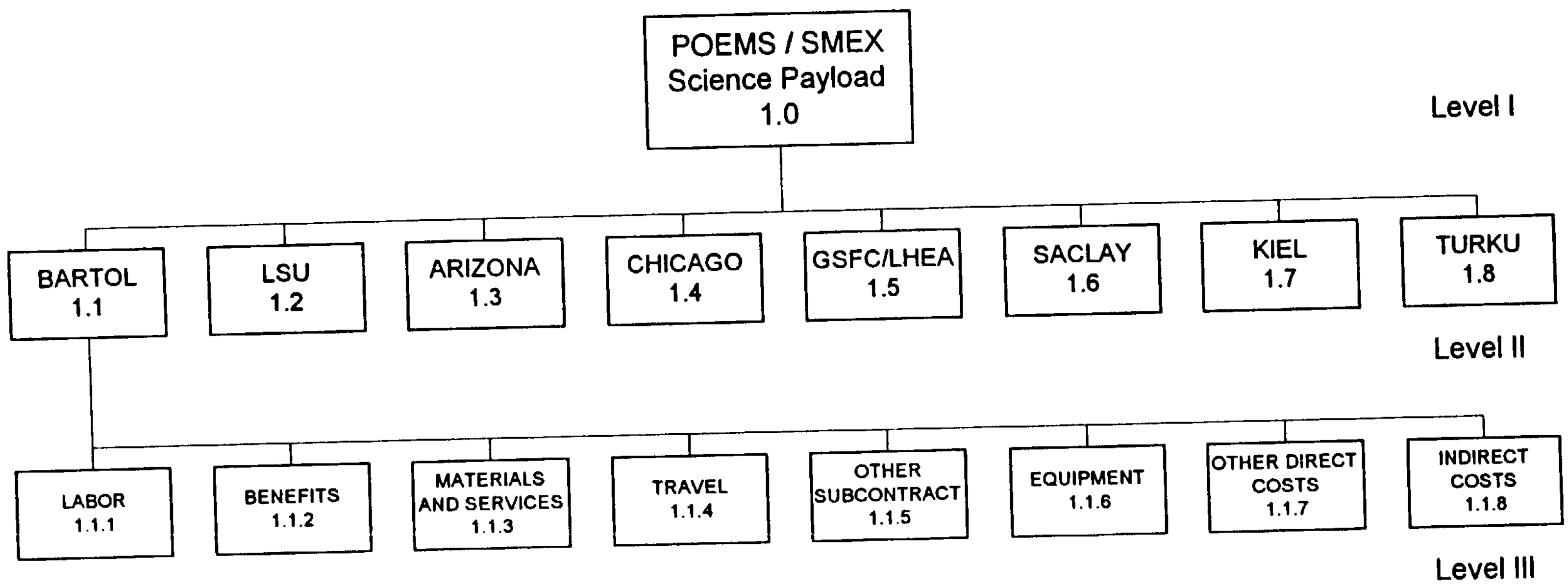
SMEX/POEMS Cost Summary for Phase III Distribution by US Collaborators



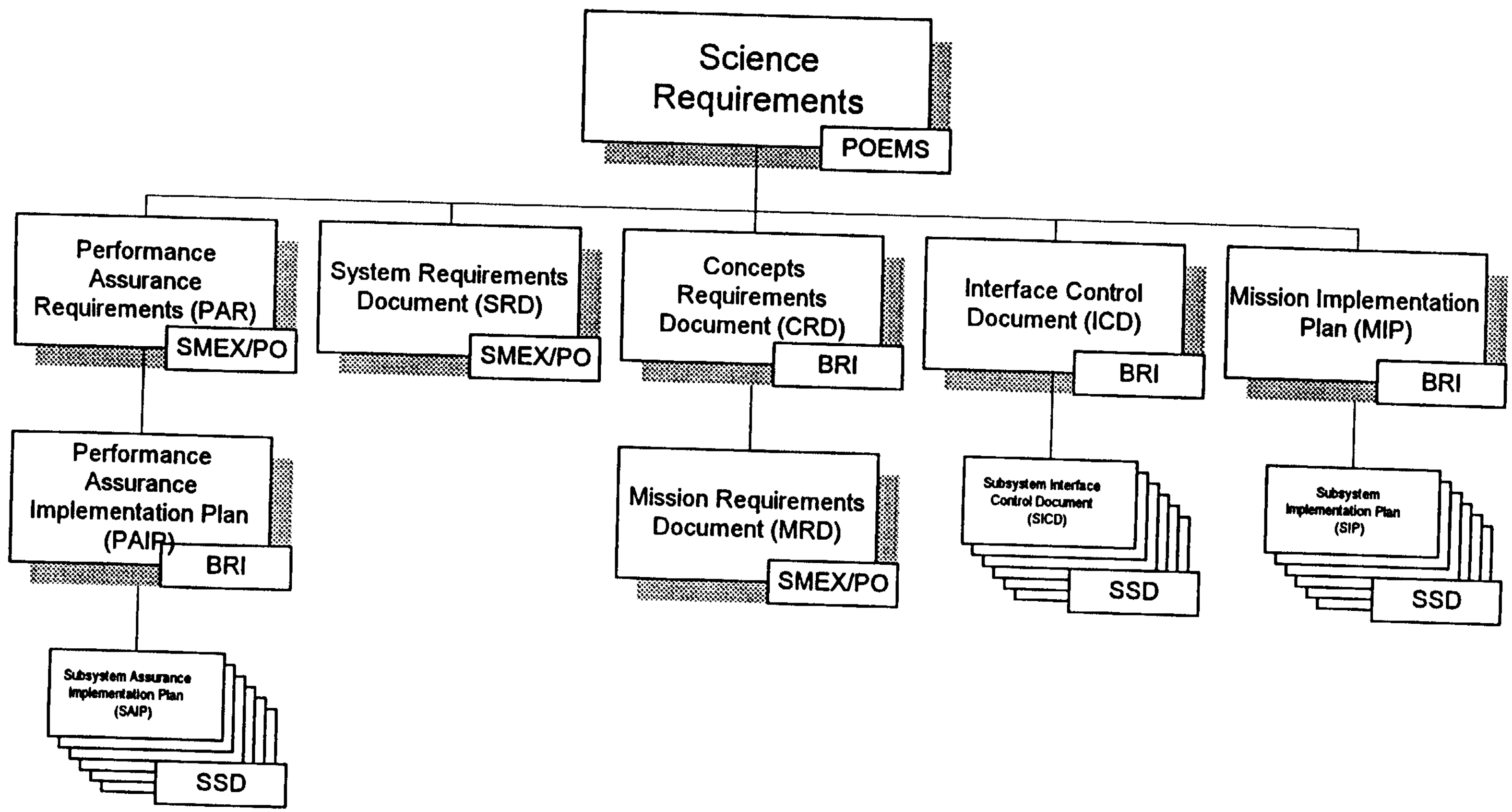
SMEX/POEMS Cost Summary for Phase III Profile by Collaborator and Sub-phase



Science Payload WBS



Document Tree for POEMS



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13. ABSTRACT *(Maximum 200 words)*

This report covers the activities of Louisiana State University (LSU) under subcontract 26053-EX between LSU and the Bartol Research Institute (Bartol), wh ich began January 1, 1994. The purpose of this subcontract was for LSU to participate in and support Bartol in the work to define the SMEX/POEMS spaceflight mission under NASA Contract NAS5-38089 between NASA and Bartol.

The conclusions of this study were that for a 1998 launch into a 600km altitude, 98°, approximately sun synchronous orbit, (a) the total radiation dose would be typically a few k-rad per year, certainly < 20 k-rad per year for the anticipated shielding and potential solar flare environment, (b) detector counting rates would be dominated by the South Atlantic Anomaly (SAA) and the horns of the Van Allen berlts, (c) the galactic electron and positron "signal" can be extracted from the albedo background and the trapped populations by detailed evaluation of the geomagnetic transmission function (cut-off) for each event, (d) POEMS could make significant contributions to magnetospheric science if sufficient downlink capacity were provided and (e) a fully functioning, cost efficient, data processing and analysis facility design was developed for the mission. Overall, POEMS was found to be a relatively simple experiment to manifest, operate and analyze and had potential for fundamental new discoveries in cosmic, heliospheric, solar and magnetospheric science.

14. SUBJECT TERMS

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